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Retrieval Inhibition In Human Memory: An Extension And Evaluation Of The Sam Theory

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RETRIEVAL INHIBITION IN HUMAN MEMORY:
AN EXTENSION AND EVALUATION OF THE SAM THEORY

by

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ABSTRACT

Retrieval inhibition occurs when related information presented during the act of remembering inhibits recall performance. In the part-list cuing paradigm subjects are presented with part of a list and asked to recall the rest of the list. A comparison with an uncued condition shows that recall is reduced by the part-list cues. This inhibition effect has proven to be quite problematic for theories of memory. Many theories propose that lists of words are learned by forming associations between the words and, thus, part-list cues should allow subjects to follow these associations and increase their recall. Although many explanations for the effects of part-list cues have been suggested, Shiffrin's SAM (Search of Associative Memory) theory of memory retrieval is the most promising. In the SAM theory the effects of part-list cues are explained by the nature of the memory associations and the related retrieval processes. The purpose of this research was to apply the SAM theory to two new retrieval inhibition situations and evaluate its performance. In Experiments 1 and 2 it was shown that part-list cues that are delayed for short periods (15 or 30 seconds) inhibit written recall while cues delayed for long periods (1, 2, or 4 minutes) have no effect. A computer simulation program based on the SAM theory was able to predict the correct effects of delayed cues in this situation. In Experiment 3 the effects

of delayed part-list cues were examined under verbal responding conditions and it was found that cues delayed for long periods (3 minutes) facilitated recall performance. However, the SAM simulation program was not able to predict the correct effects of delayed cues in this situation. In a fourth experiment the sampling rule in the SAM theory was evaluated. The SAM theory predicts that strong items in memory should block the recall of weaker items. Experiment 4 showed that the blocking effect produced by strong items is quite small, but the SAM simulation program predicted the correct amount of blocking. Thus, the present research provided important new evidence on the effects of part-list cues and the competition action of items in memory. Further, the SAM theory of memory retrieval was evaluated and although it was able to model most of the data, some important problems with the theory were discovered.

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INTRODUCTION

Retrieval inhibition occurs when related information presented during memory retrieval reduces recall performance (relative to situations where no information is presented). The classic demonstrations of this inhibition were reported by Slamecka (1968, 1969). In what has come to be known as the part-list cuing paradigm, subjects studied a list of words and then attempted to recall them either with no cues (free recall), or with half of the list members acting as cues for the remaining words (part-list cues). To equate the conditions, only the words that could be recalled by both groups (target words) were counted. The results showed that part-list cues failed to facilitate recall, and actually reduced recall scores by about 10%. This finding, that a set of related cues can inhibit recall, has been replicated and extended by a variety of researchers (see the reviews by Raaijmakers & Shiffrin, 1981; Roediger & Neely, 1982; and Nickerson, 1984).

The part-list cuing effect is rather counter-intuitive. Subjects often report that they memorize a list of words by making up stories or images that relate the words in some sequence. It should follow, then, that presenting part of the list should allow the subjects to follow their associations and recall the rest of the list. In fact, most memory theories predict facilitation in the situations where inhibition effects are actually found (e.g., Collins &

Loftus, 1975; Anderson, 1972, 1976, 1983). So far, providing a theoretical explanation of these inhibition effects has been a persistent problem for memory researchers. Until a satisfactory explanation for these inhibition effects is offered, no memory theory can be considered to be complete.

The phenomenon of retrieval inhibition is also important because it may be a model for naturally occurring memory failures and may provide information about memory failures of a more serious nature (i.e., amnesia). Also, we are often presented with memory retrieval tasks in which we are given partial or related information in an attempt to aid remembering (e.g., the help menus in the word processor I am using). In fact, we often generate partial information ourselves when we are trying to remember (R. Brown & McNeil, 1965). It might be that this partial or related information, which we think will help our recall, actually acts to inhibit our recall performance. A. Brown and Bradley (1985) showed that subjects have increased confidence in their ability to recall capital cities when the amount of related information (non-capital cities) is increased. In fact, subjects who were given more related information actually did worse than those given little or no information. Thus, people may have erroneous beliefs about what will help them to remember and, if given the opportunity, they may continue to use related information and reduce their recall performance.

Inhibition from partial or related information may also show up in non-memory tasks. During problem solving, subjects often try a few solution attempts and then perseverate on the same ideas, hindering the finding of a solution (Luchins, 1942; Weisberg & Alba, 1982). Some researchers have argued that an important element of the creative process may be the ability to avoid perseverating on early solution attempts (e.g., Woodworth & Schlosberg, 1954). On the surface at least, the inhibition seen in recall tasks and the inhibition seen in problem solving and creativity situations are very similar (Penney & Winsor, 1982; Roediger & Neely, 1982). Therefore, by gaining insight into the mechanisms responsible for memory retrieval inhibition, we may also learn something about problem solving and creativity.

On theoretical grounds, retrieval inhibition may tell us something about the nature of memory storage and the processes responsible for memory retrieval. Slamecka argued that his results were inconsistent with models of memory that propose associations between words as a result of list learning (e.g., Anderson, 1972; Tulving & Pearlstone, 1966). In such models, presentation of some list members should elicit other list members by way of associative links. On the other hand, Slamecka argued that words are stored separately with no inter-item associations. Since a large number of memory theories propose a storage structure consisting of a vast network of associative links (e.g., Anderson, 1972, 1976, 1983; Collins & Loftus, 1975; Raaijmakers & Shiffrin, 1981), the results from retrieval inhibition experiments may force these models to be changed. In fact, a number of revisions to memory theories have been proposed to explain retrieval inhibition phenomena. The purpose of this paper is to extend and evaluate one of the more promising proposals. Before this proposal is outlined, however, it is necessary to briefly review the large retrieval inhibition literature.

The Varieties of Retrieval Inhibition

Part-List Cuing

Slamecka (1968, 1969) first demonstrated that part-list cues reduce recall of the remaining target words. Roediger, Stellon, & Tulving (1977, Exp. 1) later demonstrated that the inhibition effect was directly related to the number of part-list cues provided, with target recall decreasing with increasing numbers of cues.

It should be noted, however, that not all forms of cuing produce inhibition effects. Tulving and Pearlstone (1966) found that some related information can increase recall performance. In that study, subjects studied categorized lists in which 1, 2 or 4 category instances were presented along with the category names (the subjects were instructed to only remember the category instances). The cues that were given at recall were the category names that were presented during study. Tulving and Pearlstone found that these category cues facilitated recall in comparison to a free recall group. Further, subjects who recalled all that they could without the cues were able to increase their recall performance when they were later given the category cues. Thus, there is an apparant discrepancy between the effects of category and part-list cues.

To investigate this contradiction, Roediger (1978) repeated Tulving and Pearlstone's experiment but presented subjects with only some of the category names during the retrieval attempt. He found that the cues facilitated recall of the cued catgeories and inhibited recall of the non-cued categories. Thus, the part-list cuing effect can be found at the level of categories. Also, Rundus (1973) and Roediger (1973) found that with categorized lists in which the category names were not presented during study, one category member from the list may facilitate recall of that category but further category members reduce recall performance. They concluded that ~~if~~ a list has a definite structure, and if the cues are chosen such that they give the subjects access to parts of the list they might not have access to, then the cues can be helpful. Any further cuing will have an inhibitory effect. In fact, a general consensus in the literature is that part-list cues will inhibit recall unless they provide access to "higher order units" (Roediger, 1974; Park, 1980; Wood, 1969).

Extra-List Cuing

Words that were not in the study list can also inhibit recall. Watkins (1975) had subjects study a list of 36 words made up of six instances from six semantic categories. At recall, subjects were given all the category names and 0, 2, or 4 words from each of the categories that were either part of the studied list or not in the list (extra-list cues). The results showed approximately equal inhibition effects for part-list and extra-list cues, with the inhibition effect increasing with the number of cues.

Mueller and Watkins (1977) demonstrated that the extra-list cues had to be related to the target items for inhibition to be evident. They asked subjects to study a multiple-category list and then recall the words from one of the categories. The subjects were given either relevant category members from the list as cues, or part-list cues from a different category. Only the same-category cues inhibited recall, suggesting that the effect was not due to some general interference. In a second study, Mueller and Watkins (1977) demonstrated extra-list inhibition effects when nonsemantic categories were used (e.g., rhyming or arbitrarily defined categories). In all cases, extra-list cues that were related to the to-be-recalled words inhibited recall but unrelated cues did not.

However, Roediger, Stellon, and Tulving (1977, Experiment 2) provides evidence that is inconsistent with the finding that unrelated cues do not inhibit recall. They showed that recall of random words was inhibited by extra-list cues that were unrelated to the to-be-remembered words. Perhaps a better conclusion about extra-list cues is that they will inhibit recall if they cannot be easily rejected by the subjects (Raaijmakers & Shiffrin, 1981). Cues from a different category may be easily ignored during categorized recall, but random cues cannot be ignored during recall of random lists.

Inhibition in Recognition Tasks

It has been suggested that retrieval inhibition may only be evident in tasks requiring generation of responses. Slamecka (1975) found no effect of part-list cues on recognition performance, suggesting that the effect was specific to the generation process. However, later studies have demonstrated inhibition effects in recognition memory (Todres & Watkins, 1981; Park, 1980; Neely, Schmidt, & Roediger, 1983). Although there is some evidence that recognition inhibition may be greater with extra-list cues than with intra-list cues (Slamecka, 1975, used intra-List cues), it seems safe to conclude that retrieval inhibition is not specific to recall tasks.

Retrieval Inhibition in Semantic Memory

The studies reviewed so far can be characterized as involving episodic memory (Tulving, 1972) since subjects study a list of words to be recalled after a short period.

In semantic memory tasks, subjects retrieve information from their general store of knowledge. Although it is probably impossible to find a semantic memory task that does not involve an episodic memory component, a large body of evidence suggests that recall of general information is different from recall of episodes (Tulving, 1983). Thus, it is interesting to determine if retrieval inhibition occurs in semantic memory tasks.

J. Brown (1968) demonstrated a part-list inhibition effect in semantic memory by having subjects produce names of U.S. states either with no cues, or with 25 state names as cues. The results showed decreased recall performance in the part-list cuing condition.

In further studies, A. Brown (1979) had subjects answer definition questions (e.g., "to swallow or eat greedily") either without cues, with correct cues (gobble), with related cues (cram), or with unrelated cues (feud). He found slower response times and more errors with the related cues compared to the unrelated cues. However, Roediger, Neely, and Blaxton (1983) reported that this inhibition may be due to the presence of correct cues inducing a "checking" strategy (the subjects check to see if a related cue is correct, but they do not need to check an unrelated cue), because removing the correct cues erased the inhibition produced by the related cues.

Blaxton and Neely (1983) demonstrated retrieval inhibition in a semantic memory task in which subjects generated category instances. When four related cues were presented prior to the generation task the response times were slowed. This effect was strongest when the cues were generated by the subjects. Thus, it seems clear that retrieval inhibition occurs in both episodic and semantic memory tasks.

Output Interference

Retrieval inhibition can also be produced by prior retrieval of related material (output interference). Roediger and Schmidt (1980) had subjects study a multiple-category list and then recall the words one category at a time. They found that recall performance decreased with the testing position of the category, independent of the input position of the category.

In a semantic memory task, A. Brown (1981) demonstrated that with repeated retrievals from a category, production of instances became increasingly slower. Thus, retrieval (or output) of words from memory inhibits later recall performance.

In summary, retrieval inhibition has been demonstrated in a wide variety of situations. Roediger and Neely (1982) and Nickerson (1984) suggest that the most parsimonious explanation is to propose a single mechanism for the wide variety of retrieval inhibition effects that have been discovered. A general theoretical account of retrieval inhibition would have to explain the findings in each situation. We now turn to a discussion of theories that have been proposed.

Theoretical Accounts of Retrieval Inhibition

As discussed earlier, many memory theories propose that items are stored in a large associative network. These theories suggest that part-list cues should allow the subjects to follow the associative links and gain access to target items. Thus, the theories predict facilitative effects for part-list cues, and this is not what is found. One attempt to explain retrieval inhibition is to keep the network storage assumptions, but to propose other mechanisms to explain the inhibition effects.

Disruption

Basden, Basden, and Galloway (1977) have proposed that part-list cues disrupt the normal retrieval process. More specifically, they propose that the order of output from memory is disrupted and this somehow produces the inhibition effects. The idea of associative connections within memory is retained in their account, but they propose that the normal order of recall is disrupted by the part-list cues.

This disruption explanation has received little support in the literature. Roediger et al. (1977) argue that the continuation of inhibition effects into prolonged retrieval attempts is inconsistent with this explanation. However, Nickerson (1984) points out that if the disruption produced by part-list cues allows memory for the words to decay, then this finding may not be problematic. On the other hand, this decay hypothesis cannot explain why inhibition is seen in semantic memory tasks where memories are considered to be permanent. Further, Raaijmakers & Shiffrin (1981) argue that this account cannot explain why retrieval cues are sometimes beneficial (e.g., presentation of category names; Tulving & Pearlstone, 1966) since these should also disrupt output. Therefore, the disruption model has been rejected as a general explanation by most researchers.

Cue Overload

Watkins (1975) and Mueller and Watkins (1977) have proposed that part-list cues act as additional list members that increase the length of the list. Increased list length is known to decrease the probability of recalling each list member (e.g., Tulving & Pearlstone, 1966). Mueller and Watkins (1977) consider the part-list cuing effect to be a result of "cue overload." In support of this explanation, Watkins (1975) reported experiments that showed extra-list inhibition effects to be of the same magnitude as intra-list effects, suggesting that both cue types increase the length of the list. Further, presenting additional list items inhibits recall in a similar manner (Watkins, 1975).

The cue overload model, however, cannot explain inhibition effects in semantic memory tasks where there is no list to be increased. Further, Roediger et al.'s (1977) finding of a reduced inhibition effect with extra-list cuing of random word lists is problematic for the cue overload account since these words should have overloaded the retrieval cues to the same degree as intra-list cues.

The Strength Competition Model

Rundus (1973; see also Roediger, 1973, 1974) proposed that retrieval inhibition is due to a competition process at the time of retrieval. Similar to the original proposal by Slamecka (1968), Rundus proposed that words are not directly associated in memory. Instead, a hierarchical association scheme was outlined in which list items are grouped under control elements (e.g., category names). Thus, the traditional approach of an associative network is abandoned in the strength competition model. It should be noted, however, that the important aspects of the model are independent of these storage assumptions.

The important parts of the strength competition model for the part-list cuing effect are three simple principles. First, items in memory are sampled with replacement: a recalled word can be recalled again. Second, the act of recalling an item increases the strength of that item. Third, the probability that an item will be recalled is given by a ratio rule: the strength of a particular item divided by the strength of all the items. Thus, increases in strength will increase the probability of retrieval relative to the rest of the list. This puts items in memory in competition with one another, and the strongest items will win out and be retrieved. In this model the presentation of part-list cues acts as a retrieval of the cued items and their strength is increased. The result is that the cue items tend to block target items and be repeatedly retrieved until the recall effort stops.

This strength competition model of retrieval inhibition is consistent with a large amount of data. Extra-list cuing can be explained by extending the model to allow for latent extra-list category members in the hierarchical representation. Retrieval inhibition in semantic memory can be explained by the same principles used to explain episodic inhibition effects. Output interference can be explained by assuming that previously recalled items have increased strength and a tendency to be repeatedly retrieved.

There is some evidence, however, which is inconsistent with the strength competition model. For example, Basden et al. (1977) tested the idea that strong memories block the recall of weaker memories. They prepared word lists in which target words were combined with strong or weak "filler" words. If the strength competition model is correct then the strong filler words should block the recall of the target words (in comparison to the weak filler words). They found, however, that there was no difference in target recall in these two conditions. Other tests of the strength competition model have occasionally shown the predicted blocking effect, but the issue has not been settled and the proposal should be carefully examined before it is accepted. Experiment 4 in this thesis provides a test of the ratio rule aspect of the model.

<u>The SAM Theory</u>

Raaijmakers & Shiffrin (1980, 1981) have proposed an elaborate computer model of retrieval processes (SAM, for Search of Associative Memory) which, they claim, provides a general account for retrieval inhibition. This model is very similar to Rundus's model, as they are both based on an earlier model by Shiffrin (1970). The SAM model includes the principles of sampling-with-replacement, strengthening-with-retrieval, and the ratio rule. The model differs from the Rundus model in two ways. First, the SAM model allows for inter-item associations as a result of list learning. Second, the principles mentioned above are not used to explain the part-list cuing effect, although they are used to explain output interference.

Raaijmakers and Shiffrin propose a sampling-bias explanation for the part-list cuing effect that is similar to the disruption account proposed by Basden et al. (1977). In the SAM theory, items are stored in memory as "clusters" such that there are strong associations between items in a cluster, and relatively weak associations between clusters. This means that once an item in a cluster is recalled, there is a high probability that the other items in the cluster will also be recalled.

Two kinds of sampling are proposed in the model: context-only sampling, and context-plus-cue sampling. To obtain maximum recall performance both context and context-plus-cue sampling must be used. Free recall subjects begin sampling with context alone, and any recalled items are used for context-plus-cue sampling. Cued subjects, on the other hand, begin with context-plus-cue sampling. Since the cued subjects use the cues during retrieval, the effect is to bias the search towards clusters in memory that are relatively weak in target items (since one item must be the cue that provided access). Raaijmakers and Shiffrin assume that cued and non-cued subjects will sample the same number of clusters, but while the free recall subjects will sometimes get credit for 100% of the items within a cluster (when all the items in a cluster are targets), the cued subjects will usually get credit for some smaller percentage (because the cluster was accessed via a cue item). They also assume that the subjects <u>must</u> use the cues when they are presented, and they use all of the part-list cues in the search process before they use any of the recalled items as cues.

This model of retrieval from memory is implemented by Raaijmakers and Shiffrin in a computer simulation program. Using the program they are able to show that the factor of strengthening-with-retrieval (incrementing) is not responsible for the part-list cuing effect. However, they do rely on this factor to explain output interference (Raaijmakers & Shiffrin, 1980). Output interference is explained by the recalled items being strengthened as they are recalled, such that the probability of their being sampled again is increased. Thus, Raaijmakers and Shiffrin reject Rundus' strength principles when modelling the part-list cuing effect, although they retain them to explain output interference. This strategy of proposing two separate mechanisms (sampling bias and strength competition) for the similar phenomena of part-list inhibition and output interference may not be elegant, but given the large amount of data the SAM theory is able to account for and simulate, it may be the correct approach.

The SAM theory is also able to account for the other retrieval inhibition phenomena. Raaijmakers and Shiffrin (1981) have shown that the simulation program is able to model the extra-list inhibition effects reported by Watkins (1975). (The theory has problems, however, with Mueller and Watkins (1977) finding that extra-category cues do not inhibit recall.) Further, Gronlund and Shiffrin (1986) have recently applied the SAM theory to the semantic memory domain and sucessfully modelled a part-list inhibition effect. Finally, Gillund and Shiffrin (1984) have developed a version of the SAM theory to explain recognition memory and, although they did not attempt to model inhibition effects in recognition, the theory seems to provide a reasonable account of recognition.

In summary, a number of explanations for retrieval inhibition have been proposed but the SAM theory is the strongest contender. This thesis will present four experiments designed to extend and evaluate the SAM theory.

THE SAM THEORY: A DETAILED ANALYSIS

The SAM theory of memory retrieval (Gillund & Shiffrin, 1984; Gronlund & Shiffrin, 1986; Raaijmakers & Shiffrin, 1980, 1981) is a complex theory that can be applied to a variety of memory paradigms. The heart of the theory is a computer simulation program which is used to model the results produced by human subjects. The authors have used the program to simulate a number of recall and recognition experiments with a great deal of success.

SAM can be described as a general theory that incorporates many of the features and processes that have been proposed in the history of memory research. The theory does not propose any radically new memory structures or processes, but rather it includes most of the features of previous proposals and quantifies them in a computer program. The theory includes both a short-term and a long-term store, with the former having limited capacity. The long-term store is described as an associative network where everything is connected to everything else, although some connections are stronger than others. Thus, the theory allows for inter-item connections, connections to control elements, schemas, categories, etc. In fact, the theory has been criticized because it may propose too many memory structures and processes such that any memory phenomenon could be explained by some portion of the theory.

The SAM theory emphasizes the processes involved during the act of remembering, rather than the cognitive structures responsible for storage. The main assumption of the SAM theory is that recall is a probabilistic process in which retrieval cues are used extensively. The model incorporates both a short-term and a long-term memory store, although for most purposes only recall from long-term memory is considered. Long-term memory is modelled as a complex structure of inter-item associations, similar to many other models of memory storage (e.g., Collins & Loftus, 1975; Anderson, 1972, 1976, 1983). The units of long-term memory are described as "images", and retrieval is modelled as a processes of "sampling" the images in a probabilistic fashion. (For the present purposes the images can be thought of as words from an experimental list.) Once an image has been sampled, there is a process of "recovery" in which the image is evaluated and, if enough information is available, the image is recalled.

The processes of sampling and recovery are dependent on a "retrieval structure" which represents the strengths of the relationships between various images in memory, and between the images and the overall "context". Thus, for a list of N items there is a N X 1 matrix for the context-to-item strengths, and a N X N matrix for the inter-item strengths. The strengths in this retrieval structure matrix are said to represent the amount of information that is stored during learning (regardless of the type of information). In the absence of any learning there is assumed to be a small "residual strength", but with study this strength is increased.

The process of retrieval is modelled in SAM by a combination of context-based sampling and context-plus-cue sampling. In the former an image is randomly sampled according to a ratio rule where the probability of sampling is given by an image's strength divided by the strength of all the images combined. There is also a recovery rule such that the probability that an item is recovered increases as the corresponding context-to-item strength increases. Context-plus-cue sampling is assumed to occur whenever an item is successfully recovered. Again an image is randomly sampled using a ratio rule which is now the ratio of the inter-item strength between a cue and an image divided by all the inter-item strengths for that cue. During recovery both the context and inter-item strengths are used to determine whether an item is successfully recalled.

In the SAM theory there is also a provision for strengthening-with-retrieval. When an item is sampled there is assumed to be an "incrementing" of the context-to-item or inter-item strength. In addition, there is an incrementing of an image's self-strength, the tendency for an image to cue itself.

The SAM theory also models the decisions made by the subjects during the process of retrieval. A stopping rule is proposed in which the subjects terminate search efforts once a critical number of samples have failed to recall a new word. Also, there is a stopping rule for determining when a cue word will be abandoned and context-only sampling will be resumed. Finally, the subject is assumed to do a process of "rechecking" once the main search phase of retrieval has ended. Here each of the recalled items are used as cues until their abandonment criterion is reached. This is to ensure that each cue is used to its full potential, since during normal search a cue is abandoned immediately in favour of any new item that is recalled.

The theoretical assumptions of the SAM theory are implemented in the simulation program. The program entails 10 parameters: context-to-image strength (a), inter-image strength (b), self-strength (c), residual strength (d), context-to-image increment (e), inter-image increment (f), self-strength increment (g), the total failure stopping criterion (KMAX), the criterion for cue abandonment (LMAX), and the size of the short-term memory buffer (r). Raaijmakers and Shiffrin chose values for these parameters using Monte Carlo methods in which a number of simulated "subjects" are run and the results averaged. The parameters were varied until the simulated data fit a set of data from human subjects. Once the values of the parameters were set, they were not changed unless an attempt was made to model a particular paradigm or manipulation.

Once the the parameter values were chosen, Raaijmakers and Shiffrin attempted to simulate a variety of recall findings. For our purposes the important simulations are of the part-list cuing effect, although it should be noted that one of the main attractions of the SAM theory is its ability to simulate a range of memory phenomena. For the simulations of the part-list cuing effect a list of 30 words was assumed, with 15 part-list cues presented at retrieval. The part-list cues were assumed to be used for sampling before any context-only sampling was done. This was implemented by having each part-list cue used for sampling until the _LMAX_ criterion was reached. Then, if _KMAX_ had not yet been reached, normal sampling would begin. Once the _KMAX_ stopping criterion was reached, rechecking was performed in which each recalled item was used as a cue until _LMAX_ was reached. Using these assumptions Raaijmakers and Shiffrin were able to simulate the part-list cuing effect. They then explored the conditions that might alter the size of the effect.

In their first simulation they varied the inter-image strength parameter (_b_). Slamecka (1968) found that the part-list cuing effect was equally evident for related and unrelated word lists. By manipulating the _b_ parameter, Raaijmakers and Shiffrin were able to show that the SAM program is also able to produce equal inhibition effects for different degrees of list relatedness.

In their second simulation, Raaijmakers and Shiffrin manipulated the incrementing parameters (_e_, _f_, and _g_). They found that setting these parameters to zero did not eliminate the part-list cuing effect. Thus, they argued that the mechanism of strengthening-with-retrieval was not responsible for the part-list cuing effect.

In their third simulation, Raaijmakers and Shiffrin manipulated the stopping rule, KMAX. They found that the part-list cuing effect persisted during extended retrieval attempts, thus rejecting the idea that cued subjects might terminate their search efforts prematurely. This was consistent with the findings of Roediger et al. (1977) who found that human subjects show the part-list cuing effect even when encouraged to recall for long periods of time.

Therefore, by using simulations Raaijmakers and Shiffrin have discounted the factors that others have proposed as explanations of the part-list cuing effect. The explanation that they propose is one of "sampling bias". Raaijmakers and Shiffrin argue that cued subjects use the part-list cues at the beginning of their recall attempt before they begin any context-only sampling. In contrast, uncued subjects will initially undertake context-based sampling and only later use any recalled items as cues. Thus, the context-to-image strength (parameter a in the simulations) should be important since the uncued group uses it to a larger extent than the cued group. Raaijmakers and Shiffrin show in a simulation experiment that part-list cues facilitate recall for low levels of parameter a, but inhibit recall for high levels of the parameter. No one has attempted this manipulation with human subjects, but Raaijmakers and Shiffrin suggest that part-list cues might be beneficial in situations where context-to-item strengths are low, perhaps where free recall gives very low recall levels.

To explain how sampling bias can produce the part-list cuing effect, Raaijmakers and Shiffrin describe memory as a set of clusters where there are high inter-item strengths within clusters, and relatively low strengths between clusters. Thus, if an item in a cluster is recalled then there is a high probability that the other items in the cluster will also be recalled. The sampling bias explanation is that while uncued subjects sometimes sample clusters that contain only target items (and thus get credit for 100% of the items within the cluster), the cued subjects predominantly sample clusters that have at least one part-list cue, and thus only get credit for some smaller percentage of the cluster (the targets). As an example, consider the memory representation of a 9-word list depicted in Figure 1. It is assumed that both cued and uncued subjects sample the same number of clusters. Thus, in this example if all the subjects sample two clusters, the cued subjects will sample the top two clusters and get credit for two target items. On the other hand, free recall subjects may sometimes sample the bottom cluster, along with one of the others, and get credit for five target items. Thus, in the long run the free recall subjects will show superior recall of the target items. The assumptions that underlie this sampling bias explanation (i.e., clusters in

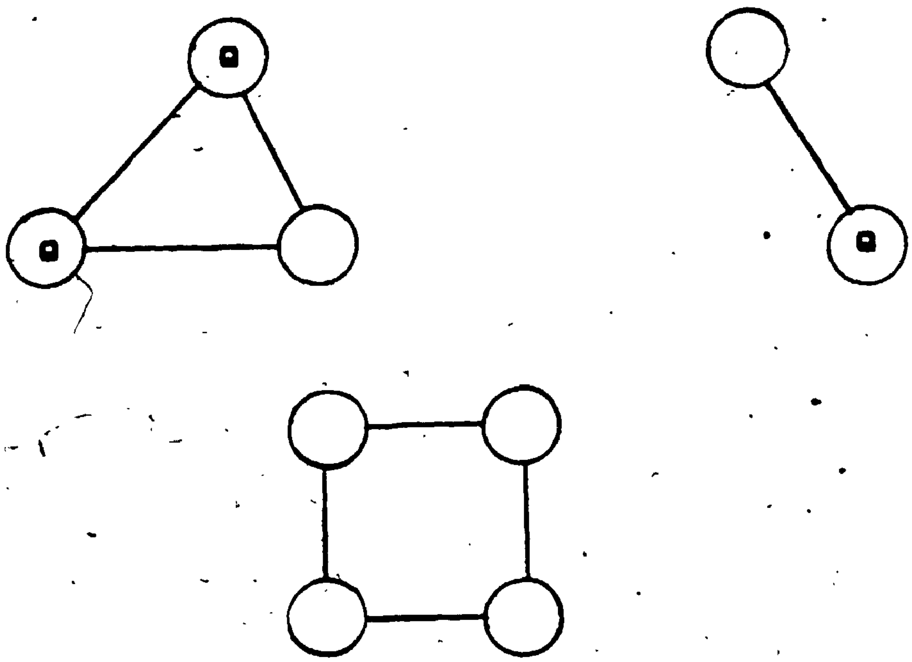


Figure 1. A memory representation of a 9-word list. Part-list cues are marked with the letter "Q."

memory, all subjects sampling the same number of clusters, etc.) could be questioned, but until contrary evidence is found they seem to be reasonable.

Thus, Shiffrin and his colleagues have provided a general theory of memory retrieval which seems to account for a wide variety of phenomena. Most important for the present purposes, SAM may provide an explanation of the problematic part-list cuing effect. It is difficult to evaluate the theory because of its complicated nature. However, Shiffrin argues that the SAM program should be applicable to a wide variety of situations with little or no change. In the next sections a set of experiments will be reported with the purpose of extending the situations to which the theory has been applied and evaluating its performance.

EXPERIMENT 1

The sampling bias explanation of the part-list cuing effect that is offered in the SAM theory entails that it is the beginning of the retrieval process that is important. Thus, if retrieval begins in the absence of cues and the cues are introduced later, the theory predicts that the cues should be facilitative rather than inhibitory. Delaying the part-list cues allows the subjects sometimes to get credit for 100% of the clusters they are able to access on their own. Further, the delayed cues may provide access to otherwise inaccessible clusters resulting in enhanced recall performance.

Raaijmakers and Shiffrin (1981) explored this delayed cue prediction using computer simulations. They had the program sample until the KMAX criterion (the stopping rule) was reached, and then in one condition they introduced part-list cues to be sampled for LMAX failures each (the criterion for cue abandonment), while in another condition recall continued for an equal number of samples. Thus, they modelled a situation where subjects recalled all that they could without part-list cues, and then some subjects were provided part-list cues while other subjects continued to free recall. (No distinction was made between cues that had already been recalled and cues that had not been recalled.) In this situation the SAM simulation program predicted a cued recall superiority of .7 words (4.7%), in contrast to the usual inhibition effect. It is this prediction of a reversal of the effect of part-list cues when those cues are delayed that will be tested in the first three experiments.

Raaijmakers and Shiffrin (1981) report that a study by Allen (1969) provides evidence consistent with their delayed cue prediction. In Allen's second experiment, subjects studied 36 pairs of words and then recalled these words for 5 minutes in the absence of cues. Following this, the subjects were either presented with one member from each pair as cues, or they were not given cues for a second recall attempt. In this experiment, cued subjects recalled more additional words in the second test than the noncued subjects: a reversal of the usual part-list cuing effect.

Although Allen's (1969) experiment appears to support the predictions of the SAM theory, the study is problematic. The use of paired words as the to-be-remembered materials provides a structure in the lists which may erase any inhibitory part-list cuing effects. A general principle that has emerged in the part-list cuing literature is that part-list cues may benefit recall if they provide access to "higher order" units that are normally inaccessible (e.g., Roediger, 1974; Park, 1980; Wood, 1969). This principle was demonstrated with categorized lists, but it is possible that word pairs provide organizational units similar to semantic categories. In fact, in Allen's experiment only the "related" word pairs showed a significant positive delayed cuing effect, with the effect for the unrelated pairs being only marginally significant ($p<.10$). Thus, in Allen's experiment part-list cues may not have produced inhibition even under immediate cuing conditions so a true reversal may not have occurred.

A second problem is that the 5 minute free recall interval that preceded the delayed cues may have been sufficient to allow the subjects to report all the accessible words. Since productive retrieval may have ceased, the part-list cues could be beneficial or have no effect, but they could not be inhibitory. These flaws in Allen's (1969) study suggest that support for the delayed cue prediction may be questionable.

In fact, another experiment reported by Allen (1969, Experiment 1) provides evidence that delayed part-list cues may have the same inhibitory effect as immediate part-list cues. In this experiment subjects studied the same 72 words used in the previous experiment one at a time in a random order, and were then tested (repeatedly) in two phases. In the first phase they recalled as many words as possible in the absence of cues until no responses had been produced for 1 minute. In the second phase, the subjects were either given 12 list cues, 12 unrelated extra-list "cues", or no cues for an additional 3 minute recall test. The results showed no significant differences in additional items recalled between these 3 conditions, with a trend for the list cues to inhibit recall performance. Thus, these results are inconsistent with Raaijmakers and Shiffrin's predictions for delayed part-list cues. Further, the absence of a list structure in this experiment makes it more representative of the usual situations where part-list inhibition is seen.

In another study that used delayed part-list cues, Slamecka (1968, Experiment 5) had subjects study a random list of 30 rare words before recalling in the absence of cues for 4 minutes. Following this test, the subjects were either given half of the words they had failed to recall for an additional 4 minute recall test, or they continued recalling without cues. After taking into account the reduction in possible words recalled in the cued condition, the results showed no difference in additional words recalled for the cued and uncued groups.

Therefore, the psychological evidence used by Raaijmakers and Shiffrin to support the delayed cuing prediction of their SAM theory is questionable. In none of these studies was it demonstrated that immediate part-list cues would produce inhibition, so a clear reversal of the part-list cuing effect was not seen. Further, each of the studies used very long delays for the part-list cues such that few items were being retrieved when the cues were introduced. This means that the cues could facilitate recall or have no effect, but they could not inhibit recall.

Raaijmakers & Shiffrin's simulation of delayed part-list cuing can also be questioned. It is possible that immediate part-list cues would have produced a positive effect when the retrieval attempt was extended beyond the normal stopping criterion. Since Raaijmakers and Shiffrin did not include an immediate cues condition and did not measure recall performance throughout the retrieval attempt, they have not shown a true reversal of the part-list cuing effect. Raaijmakers and Shiffrin also simulated retrieval without the process of "rechecking." During rechecking each of the recalled items are used as a cue for context-plus-cue sampling. Rechecking was proposed to ensure that each recalled item is used to its full potential since during normal free recall a cue is abandoned immediately if a new item is recalled. Omitting rechecking from the simulations means that once an item is recalled and used to the criterion for cue abandonment (LMAX), it is never used again. It may be more reasonable to assume that subjects periodically use their recalled items as cues, especially if the recalled items are available on a response sheet. Thus, it may be more appropriate to include the process of rechecking in the SAM simulations.

In summary, the true effects of delayed part-list cues have yet to be determined. The previous empirical research has been seriously flawed and the predictions from the SAM theory may be based on faulty assumptions. The first goal of this thesis, then, was to determine the true effects of delayed part-list cues and determine if the SAM theory is able to accurately model the empirical results.

The subjects in the first experiment were tested in four study-test trials representing four experimental conditions. For each trial a different single-category list was presented, followed by a math question distractor to reduce short-term memory. All subjects were then given two minutes to recall the list, marking their recall page after 15 and 30 seconds. In a Free Recall condition no cues were given during this test. In an Immediate Cues condition one third of the list was provided as part-list cues at the beginning of the recall period. These two conditions, then, represent the standard part-list cuing paradigm.

In a third condition, subjects were given the part-list cues after a short delay of 15 seconds, during which they attempted uncued recall. In another condition the cues were presented after 30 seconds of free recall. On the basis of the SAM model it was predicted that the immediate cues would result in reduced recall compared to the free recall condition, while the two delayed cue conditions would result in greater recall than the free recall condition. Delays of 15 and 30 seconds were chosen so the subjects' recall efforts would not have stopped and, thus, it is possible for either inhibition or facilitation to be seen.

Method

Subjects

The Psychology department at the University of Western Ontario operates a human subject pool in which introductory

Psychology students are asked to participate in five hours of experimentation as a requirement for the course. The students have the option of refusing to participate in any experiment that they find offensive or uncomfortable, and they can choose to substitute short reports for any of the five hours that are required. The subjects in the pool have a median age of 19 years.

Forty-eight students (33 females) from the subject pool participated in this experiment. Each subject was tested individually in a session lasting approximately 45 minutes.

Materials

The to-be-remembered words for this experiment were selected from the Battig and Montague (1969) category norms. Four 24-word lists were developed, with the words in each list drawn from a single category. Single-category lists were used to make the memory task less difficult and to reduce inter-list interference. The four categories used were: parts of a building, parts of the body, sports, and clothing. The word lists were gathered from the category norms by omitting the 10 most frequent responses and then selecting the next 24 single-word responses with the criterion that none of the words could be highly similar in meaning. Once the word lists were selected, the items were placed in a random order.

Procedure

Each subject was tested in four experimental conditions and the order of the conditions was counterbalanced across subjects by a Latin Square procedure. To ensure that conditions were not confounded with materials, an independent Latin Square was used to counterbalance the word lists. The combination of these two 4 X 4 Latin Squares ensured that, across 16 subjects, each condition was tested in each serial position using each word list.

The part-list cues in this experiment were 1/3 of the study list (8 words) chosen by selecting every third word in the (randomly ordered) list beginning with either the first, second, or third word. The cues were then randomized again before they were presented. This produced three cue sets and the Latin Square procedures were repeated for each set. The subjects were randomly assigned to a cue set by a predetermined pattern.

The presentation of materials and timing of the experiment were controlled by an Apple II computer. In the study portion of each trial the 24 words from one list were presented on a CRT screen for 1 second each, with a 1/2 second between words. Following this presentation sequence, the subjects solved mathematics questions for one minute by multiplying two (random) two-digit numbers.

The subjects then attempted to recall the list of words by writing their responses on a recall sheet. They were told to listen for "beeps" from the computer and look to the screen for new instructions when these occurred. In all conditions the computer "beeped" after 15 and 30 seconds. The new instructions asked the subjects to draw a line across their page under the last word they had written and continue recalling. Also, cues were sometimes presented at these times. The part-list cues were presented on the CRT screen (all at once) and described as important "clues" that would aid recall. The subjects were encouraged to use the cues when available, but not to waste time by writing (or erasing) them.

In the Free Recall condition no part-list cues were provided during the recall interval. In the Immediate Cues condition the subjects were given 1/3 of the list as cues for the entire recall interval. In the 15 second Delay condition the subjects free recalled for 15 seconds and then were provided with cues for the remaining time. In the 30 second Delay condition the subjects free recalled for 30 seconds before being provided with cues for the remaining time.

To introduce the subjects to this procedure, a practice study-test trial was given prior to the experimental trials. This practice trial used 10 vegetable names selected from the Battig and Montague norms in the manner described above. The trial was conducted according to the 30 second Delay procedure with 4 of the words given as cues after 30 seconds of free recall.

Results

Recall performance was scored by counting only the 16 non-cue (target) words. For the Free Recall condition the cue items were never presented as "clues", but to equate the conditions these cue items were omitted from the scoring. The recall results in the form of cumulative recall functions for the 2 minute recall intervals are presented in Figure 2. It should be noted that although the functions appear to have not reached asymptote, this is a product of the infrequent measurements taken. In fact, most of the subjects had finished their recall attempts before the 2 minute time limit.

Inspection of Figure 2 shows that the Immediate Cues condition resulted in lower recall performance compared to the Free Recall condition at 15, 30, and 120 seconds. Thus, the usual part-list cuing effect was obtained. It can also be seen that the two delayed cue functions have a sharp *downward* bend at the point where the part-list cues were introduced. Therefore, recall performance decreased (in relation to free recall) with the introduction of part-list cues at each delay tested.

This pattern of results was confirmed by statistical analyses. A 4 X 3 ANOVA with Condition and Time as the factors (both within subjects) revealed significant main effects for Time, $F(2,94)=26.85$, $MSe=4.24$, and Condition, $F(3,141)=5.04$, $MSe=1.84$, and a significant interaction of

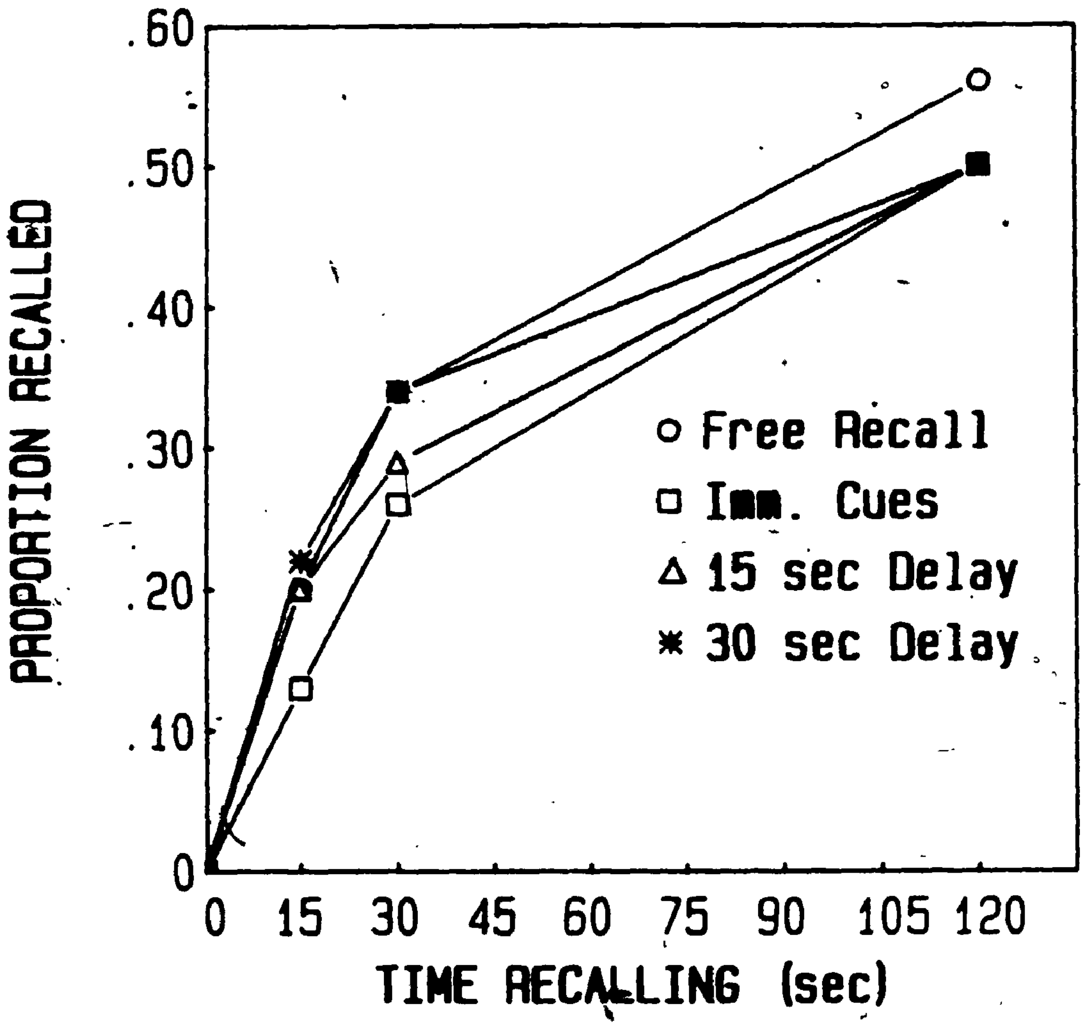


Figure 2. Experiment 1: Mean proportion of target words recalled in four experimental conditions as a function of time spent recalling.

Time X Condition, $\underline{F}(6,282)=151.98$, $\underline{MSe}=2.87$. (A significance criterion of .05 was adopted for all the analyses in this thesis.) Planned comparisons were conducted at each time point in the recall interval. After 15 seconds, the Immediate Cues condition had lower recall performance than the other three conditions (approximately 7%), which did not differ from each other. After 30 seconds, the Immediate Cues and 15 second Delay conditions were lower than the 30 second Delay and Free Recall conditions (approximately 6%), with no difference between the means in each pair. After 120 seconds, the Immediate Cues, 15 second Delay, and 30 second Delay conditions all were lower than the Free Recall condition (approximately 6%) while not differing from each other. The results, then, are very clear. Recall performance decreased with the introduction of either immediate or delayed part-list cues.

Discussion

This experiment tested an important prediction from Raaijmakers and Shiffrin's (1980, 1981) explanation of the part-list cuing effect. Their SAM theory predicts that delayed part-list cues will have an effect opposite to that of immediate part-list cues (i.e., they will facilitate recall). The results of this experiment are clearly inconsistent with this prediction. Cues that were delayed for 15 or 30 seconds inhibited target recall to the same extent as immediate cues.

In fact, by the end of the recall attempt all the cued conditions showed the same recall performance (50%). If the cues act to bias search one might expect the effects of the cues to be reduced with delayed cuing. The delayed cue subjects are allowed to do some context-based sampling before the cues are introduced, so their results should be higher than immediate cues subjects' who are not allowed any context-based sampling. Further, with delayed cues some of the cued items may have already been recalled and used for sampling before they are presented as "clues". The finding of equal final recall levels for the immediate and delayed cues conditions is a curious result that should be explored in future research.

Since the delayed cue prediction is important to the SAM theory, the results of the present experiment lead one to question the accuracy of the theory. However, Raaijmakers and Shiffrin could suggest that the delays used in this experiment were not long enough to produce a reversal of the part-list cuing effect. For instance, in the study that showed a positive effect (Allen, 1969, Experiment 2) the cues were delayed for 5 minutes. Further, the SAM simulation that showed a positive effect for delayed cues assumed that the cues were not introduced until the normal stopping criterion was reached. Perhaps with the relatively short delays tested in the present experiment the sampling bias mechanism still directs subjects to clusters that are weak in target items when the cues are introduced.

This argument seems unlikely since in the 30 second Delay condition the cues were introduced after subjects had recalled 61% of the words they would ever recall in the Free Recall condition. It is difficult to see how the sampling bias described by Raaijmakers and Shiffrin could operate this late in the retrieval process. Further, if the delay had been longer the recall levels would be close to asymptote, leaving little room for inhibition. Nonetheless, the possibility exists that cues introduced very late in the recall process might produce positive effects. These cues may give the subjects access to clusters in memory that they had not accessed on their own, and this could lead to increased recall performance. In the next experiment the cues were introduced after much longer delay intervals.

EXPERIMENT 2

This experiment was designed to test the effects of delayed part-list cues when those cues are introduced late in the retrieval attempt. In Experiment 1 it was found that cues introduced after 15 or 30 seconds of recall produce quite large inhibition effects. However, it could be argued that those delays are not long enough to test the predictions of the SAM theory. The previous empirical research and the SAM simulations suggest that part-list cues may have a positive effect once the normal retrieval process has become fruitless. Thus, in this study subjects were given an extended time limit for their recall attempt (5 minutes), and the part-list cues were introduced after either no delay, a 1 minute delay, a 2 minute delay, or a 4 minute delay.

Method

Subjects

Thirty undergraduates (24 females) from the University of Western Ontario subject pool participated in the study. (In fact, more than 30 subjects were tested for this experiment but the results from some subjects were not included because they failed to follow the instructions. The actual number of subjects that were dropped and replaced for this reason was not recorded.) The subjects were tested in groups of 1 to 4 in a session lasting 1 hour. Each group was randomly assigned to a counterbalancing cell (described below).

Materials

The words that made up the study lists were selected from the Paivio, Yuille, and Madigan (1968) norms using the criteria that they be familiar (A or AA on the Thorndike & Lorge, 1944, word frequency count), concrete (concreteness ratings greater than 4.99), and 3 to 6 letters in length. These criteria lead to a pool of 136 words, from which 5 24-item word lists and 1 12-item practice list were randomly drawn. Each list was randomly divided into two equal size sub-lists that were used to provide part-list cues and target items.

Procedure

Presentation of the materials and timing of the tasks was controlled by an Apple II computer. During study the words to be remembered were presented on a computer screen for 2 seconds each (.5 seconds between words). Following the study phase, the subjects solved multiplication problems for 1 minute and then attempted to recall the words. Five minutes were provided for recalling each list, and the subjects were trained to draw lines under the last word written when a computer-generated tone sounded after 30 seconds, 1 minute, and every minute thereafter. (This training proved to be quite difficult and some subjects had to be replaced for failing to draw all the lines in all the trials.)

Five different testing conditions were examined: free recall, immediate part-list cues, or part-list cues delayed for 1, 2, or 4 minutes into the recall period. The part-list cues were presented on the computer screen and the subjects were instructed to use them as "clues" for the memory test. All subjects studied and recalled 5 lists of 24 items, with each list tested under different testing conditions. The order of testing the conditions and using the lists was counterbalanced by a Graeco-Latin Square procedure and the two sub-lists were used equally often as part-list cues such that across 10 cells (3 subjects each) conditions, lists, testing order, and cue set were not confounded.

Prior to doing the five study-test trials, each subject did a practice trial involving studying 12 words, 1 minute of math questions, and then 2 minutes of recall with part-list cues provided after 1 minute.

Results

The usual method of scoring only target (non-cue) words for all the conditions (including free recall) was employed here. The cumulative recall functions for each condition across the 5 minutes of recall are shown in Figure 3. It

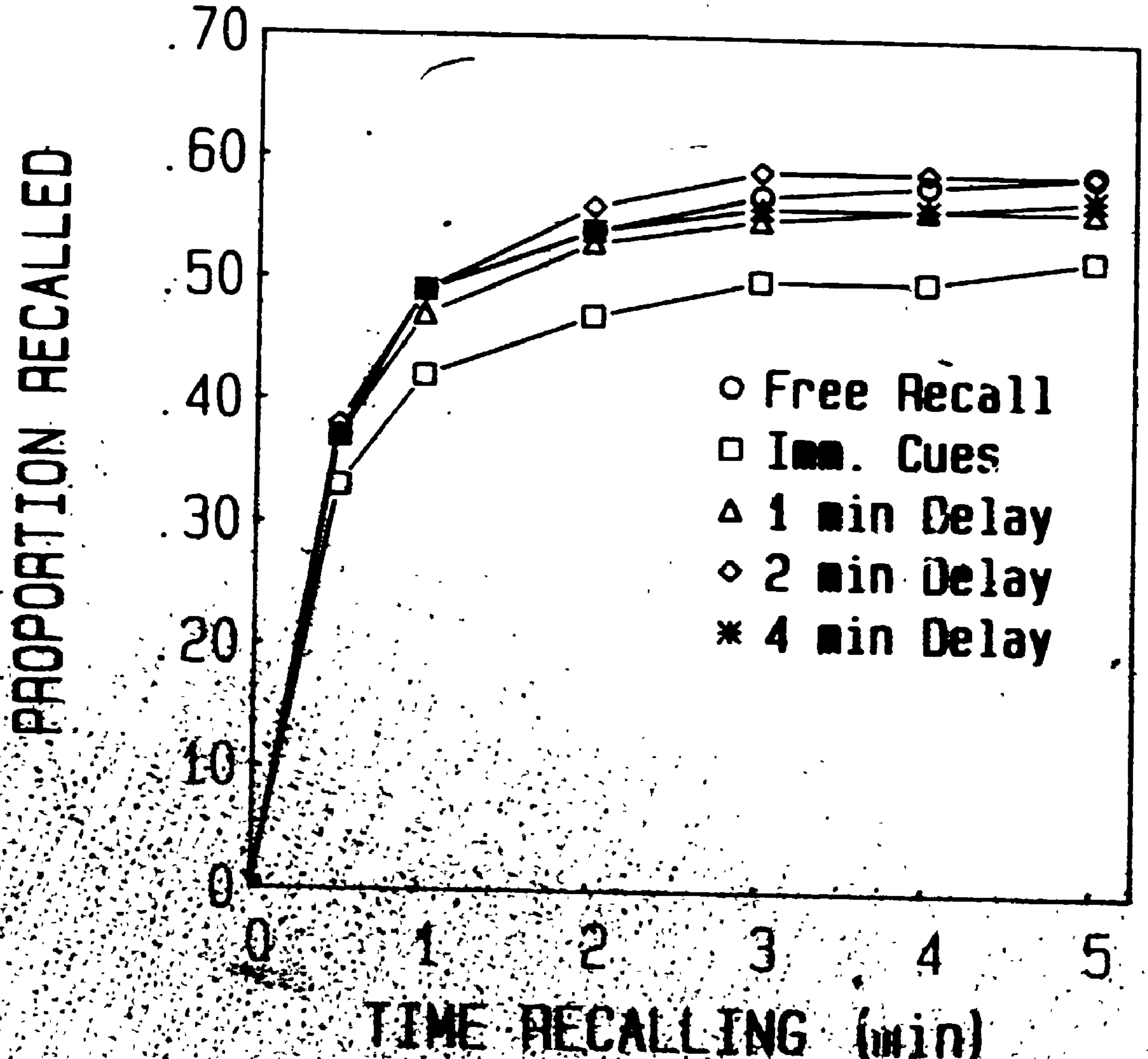


Figure 3. Experiment 2: Mean proportion of target words recalled in five experimental conditions as a function of time spent recalling.

can be seen that immediate part-list cues tended to reduce recall relative to free recall conditions (approximately 7%). Further, it appears that the 1 minute delay condition may produce slight inhibition, as would be expected in light of the results of Experiment 1. However, there seems to be little or no effect of part-list cues that were delayed for 2 or 4 minutes.

A 5 X 6 ANOVA was conducted with Condition and Time as the factors (both within subjects). This analysis revealed a significant main effect of Time, $\underline{F}(5,145)=68.78$, $\underline{MSe}=1.901$. The effect of Condition did not approach significance, $\underline{F}(4,116)=1.3$, $\underline{p}=.27$, and the $\underline{F}$-ratio for the interaction was less than 1. Thus, although the data in Figure 3 show that the Immediate Cues condition tended to produce lower mean levels of recall, the differences were not large enough for statistical significance. Further, separate ANOVAs conducted at each time interval also failed to show significant effects of Condition.

To further test for differences in the recall functions, the data were analyzed for the amount recalled during particular periods in the recall attempt. To examine the amount recalled in the last minute the recall scores after 4 minutes were subtracted from the final (5 minutes) scores. This variable expresses the growth in recall performance over the last minute. If the cues introduced after 4 minutes have an effect it should show up here. However, an analysis using this variable showed no significant differences between any of the conditions ($F<1$). Similarly, an examination of the last 3 minutes and the last 4 minutes of the recall attempt also showed no significant differences between the conditions. Thus, there were no significant differences in the recall functions at any point during the retrieval attempt.

Discussion

Although the present study failed to obtain a significant negative effect of immediate part-list cues, the results are still useful for evaluating the SAM explanation of part-list cuing. There is no evidence in the recall functions that the delayed part-list cues have the positive effect that was predicted by the SAM theory. In fact, cues introduced after a 1 minute delay seem to produce some inhibition, while cues introduced after 2 or 4 minutes have no effect at all. The SAM theory predicts that delayed part-list cues will have a positive effect, and clearly this prediction is not supported.

In this experiment it is clear that subjects' recall efforts had become fruitless after 3 or 4 minutes because the recall functions had asymptoted. Thus, any cuing that is introduced after this time can only have a positive effect, or no effect at all. Raaijmakers and Shiffrin argue that part-list cues introduced at this point should be beneficial because they can provide access to clusters in memory that have not been accessed. It is clear from these results that this description of the effects of part-list cues is in error. However, Raaijmakers and Shiffrin's (1981) simulation of delayed part-list cues may have involved some unreasonable assumptions. In the next section a series of SAM simulations are reported to determine if an updated version of the SAM program is able to simulate the correct effects of delayed part-list cues.

SAM Simulations of Delayed Part-List Cuing

The development of the SAM theory has relied heavily on computer simulations. Simulations are useful for ensuring that theories are specific and complete. To model a theory in a computer program one must be very explicit about the principles and processes that are proposed. Simulations also allow a theorist to work with complicated proposals that have many interacting components. Further, simulations can be used for evaluating and revising a theory: if a program fails to simulate an established phenomenon then a revision in the theory is called for. Richard Shiffrin and his colleagues (Gronlund & Shiffrin, 1986; Raaijmakers & Shiffrin, 1980, 1981; Gillund & Shiffrin, 1984) have used the SAM program to develop a general theory of memory retrieval and they are able to simulate a wide variety of memory phenomena. Further, when the program has failed to simulate a particular phenomenon they have revised the theory (and the program) until the finding can be modelled and accounted for.

Raaijmakers and Shiffrin (1981) reported a simulation which showed that delayed part-list cues facilitate recall. However, the results of the first two experiments in this thesis suggest that cues delayed for short periods have an inhibition effect and cues presented after long delays have no effect. This section will determine if a new version of the SAM program can correctly simulate these results.

Richard Shiffrin was kind enough to provide an updated version of the SAM simulation of part-list cuing (see the Appendix). This latest program incorporates a weighting principle for sampling and recovery (Gronlund & Shiffrin, 1986; Smythe, 1986). In the original theory (Raaijmakers & Shiffrin, 1981) the probability of sampling (P(s)) using both context and a cue was given by the ratio rule:

$$P(s) = \frac{S(C,W)_i \, S(W,W)_i}{\sum S(C,W)_i \, S(W,W)_i}$$

where S(C,W) is the strength between the context and an image, and S(W,W) is the strength between the cue and an image. Shiffrin has recently revised this sampling rule such that the context-to-item strength and the cue-to-item strength are weighted to reflect the number of cues being used. Thus, the sampling rule for context-plus-cue sampling becomes:

$$P(s) = \frac{S(C,W)_i^{1/2}\ S(W,W)_i^{1/2}}{\sum S(C,W)_i^{1/2}\ S(W,W)_i^{1/2}}.$$

Similarly, the recovery rules have been revised so the strengths that determine the probability of recovery are weighted. Now if an item has not been sampled previously the strengths are used with full weight. However, if recovery has failed in the past then any new recovery attempts use strengths that are weighted by 1/2.

In the new version of SAM there is no stopping rule for terminating a recall attempt (KMAX). Instead, it is assumed that a recall attempt is continued until maximum performance is reached and recall is traced in a cumulative fashion. Smythe (1986) tested this new version of the SAM theory by attempting to simulate the part-list cuing effect. Again the SAM program was successful in producing part-list inhibition, and the same sampling bias mechanism was implicated. The purpose of this section is to determine if the program can correctly simulate the effects of delayed part-list cues.

One of the flaws in Raaijmakers and Shiffrin's simulation of delayed part-list cuing was that recall performance was not traced throughout the retrieval attempt. The new version of the SAM program (Smythe, 1986) corrects this flaw by recording recall in a cumulative fashion as a function of the number of samples that are made during retrieval. A second problem in Raaijmakers and Shiffrin's simulation was the omission of the rechecking process. In the new SAM program rechecking can be set to occur periodically during recall, and this is more appropriate for modelling normal (written) recall.

The new SAM program includes 10 free parameters that must be set. These parameters represent assumptions about associative strengths, number of samples, short-term memory capacity, etc. The parameter values used for the present simulations were the ones used by both Raaijmakers & Shiffrin (1981) and Smythe (1986): $\underline{a}$=.1 (context-to-item strength), $\underline{b}$=.1 (inter-item strength), $\underline{c}$=.1 (self strength), $\underline{d}$=.01 (residual strength), $\underline{t}$=2 (study time), $\underline{r}$=4 (short-term buffer size), and $\underline{LMAX}$=3 (the criterion for abandoning a cue). The only departure from the standard parameter settings was that the incrementing parameters ($\underline{e}$, $\underline{f}$, and $\underline{g}$) were all set to zero. Raaijmakers and Shiffrin (1981) found that the SAM program could simulate the part-list cuing effect without using these parameters. Further, the interesting feature of the SAM theory is how it differs from Rundus's (1973) strength competition model. Rundus's model requires incrementing to explain the part-list effect while the SAM theory does not. Thus, incrementing was not included in these simulations in order to evaluate the unique features of the SAM theory.

For all the simulations a list of 30 words was assumed with 15 items used as part-list cues. Five hundred statistical "subjects" were run in each condition and the results were averaged. The strategy that was adopted for the simulations was to alter as few parameters as possible. In fact, in most of the simulations reported in this thesis the only parameters that were ever varied are LMAX (the criterion for abandoning a cue) and the total number of samples.

For the first simulation the LMAX parameter was set to 3 on the basis of simulations reported by Raaijmakers and Shiffrin. The only parameter that remained to be set was the total number of samples. The criterion that was used to set this parameter was to choose a value that allowed the recall functions to reach asymptote (like the functions obtained in Experiment 2). Some initial testing showed that a total of 400 samples (with rechecking every 100 samples) gave recall functions with the appropriate shape. Using these paramater values, a standard part-list cuing experiment was simulated where recall was tested both with and without part-list cues. Following the procedure used by Raaijmakers and Shiffrin (1981) and Smythe (1986), the part-list cuing manipulation was implemented such that each cue was used for context-plus-cue sampling until the abandonment criterion was reached (LMAX). Once all of the part-list cues had been used for sampling, normal free recall was assumed to occur until the maximum number of samples was reached.

The results of the simulation experiment are shown in Figure 4. It can be seen that there is an inhibitory part-

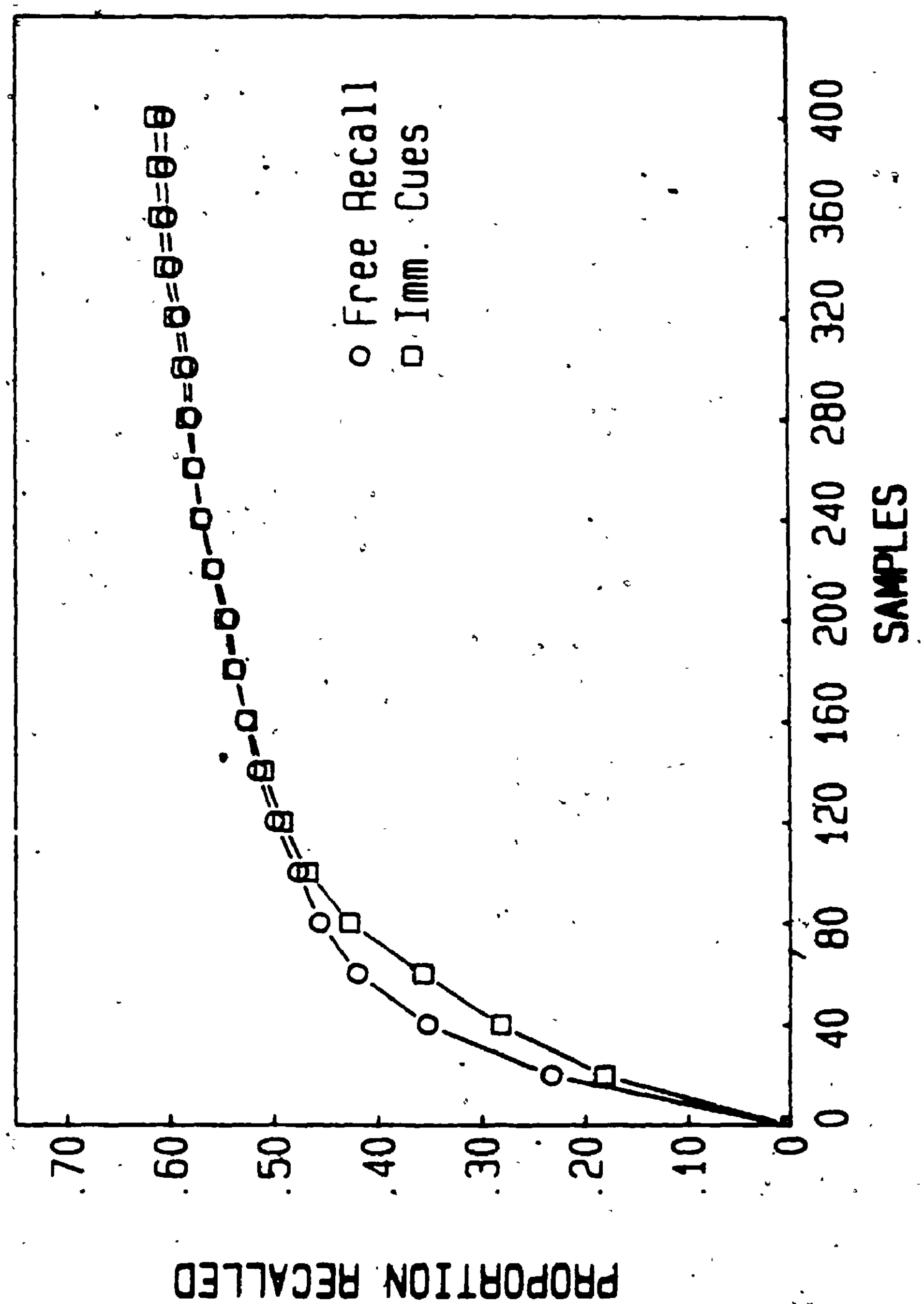


Figure 4. Simulation of target recall for Free Recall and Immediate Cues conditions as a function of the number of samples. (LMAX=3, rechecking after every 100 samples.)

list cuing effect for the first 100 samples, but then the effect becomes slightly facilitative. This reversal of the part-list effect is not due to the process of rechecking because re-running the simulation without rechecking lead to an even larger cross-over of the functions, as can be seen in Figure 5.

The cross-over of the recall functions was not seen in the early simulations of part-list cuing experiments (Raaijmakers & Shiffrin, 1981, showed a convergence of the functions after about 100 samples), and it is inconsistent with the results obtained by Roediger et al. (1977). Roediger et al. (Experiment 1) showed that the difference between free recall and cued subjects persists during long recall attempts (10 minutes for 48-item lists). Further, the subjects continued to show slight increases in their recall functions in the last few minutes, suggesting that they had not ceased recalling. Thus, while the SAM theory predicts a reversal of the part-list cuing effect in the latter part of a retrieval attempt, an inhibition effect is shown by human subjects regardless of the length of the retrieval attempt

It is difficult to reconcile this contradiction between the empirical data and the theoretical predictions, because we have no way of determining how the number of samples corresponds to time spent recalling. In order for the SAM program to accurately simulate the part-list cuing effect it must be assummed that recall stops after fewer than 100

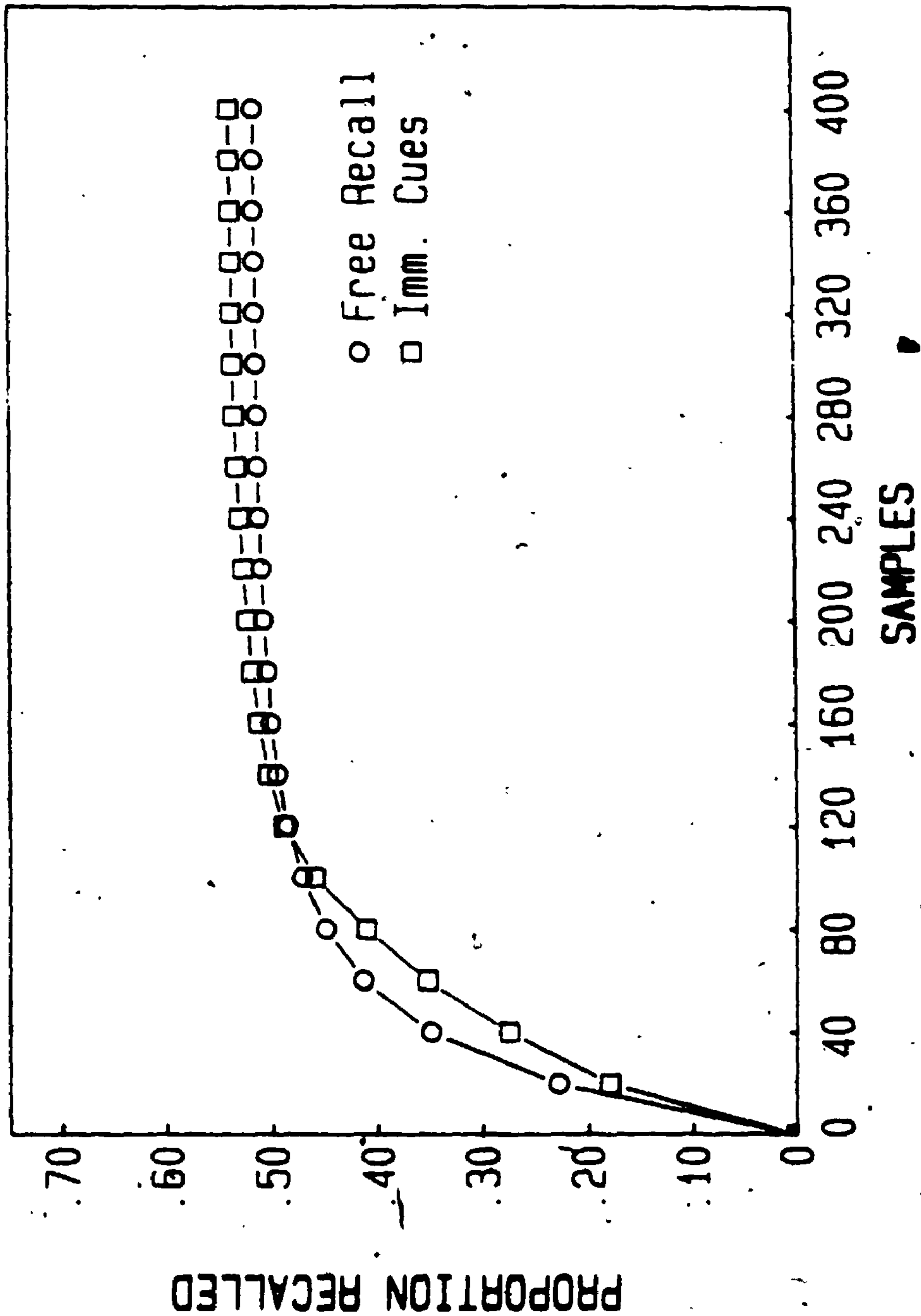
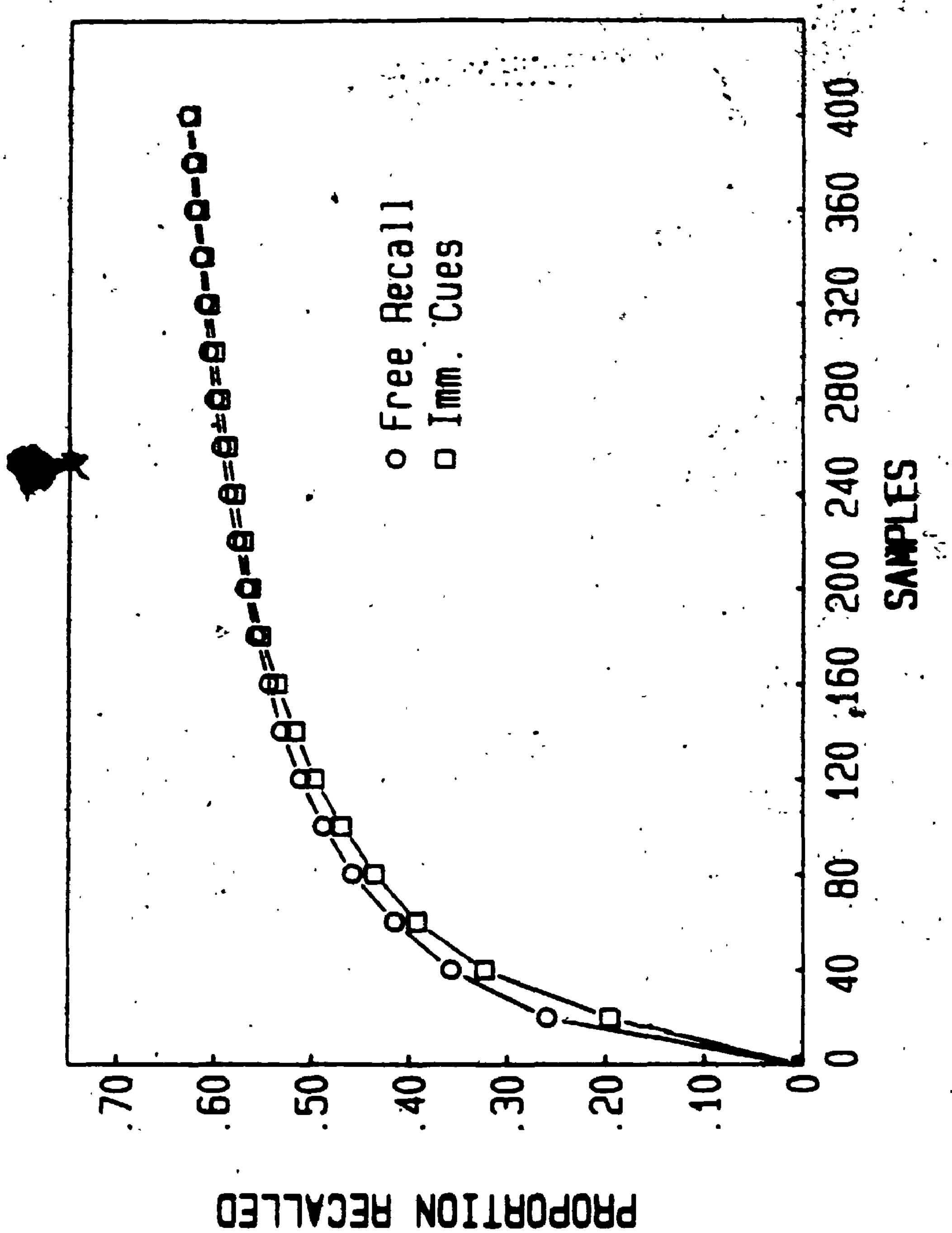


Figure 5. Simulation of target recall for Free Recall and Immediate Cues conditions as a function of the number of samples. (LMAX=3, no rechecking.)

samples. If a total of 60 samples is assumed then a part-list effect of approximately 6% is obtained, and this is comparable to the results reported in the literature and the results of Experiments 1 and 2 in this thesis. However, the recall functions at 60 samples are increasing at a faster rate than the near-asymptotic functions found in Experiments 2 (and those reported by Roediger et al.). Again, though, it is difficult to compare number of samples in the simulation experiment with the passage of time in a real experiment. Perhaps the time interval between samples grows longer as a recall attempt progresses. If this factor were built into the simulations the recall functions would begin to match the empirical functions.

In Raaijmakers and Shiffrin's (1981) original simulations a stopping rule (KMAX) of 30 failures was used, and this corresponds to approximately 50 samples. With this stopping rule the program was able to simulate the data from a variety of paradigms and, thus, it is reasonable to again limit the number of samples. A problem with using a total of less than 100 samples is that the process of rechecking is not allowed to occur. During rechecking each of the previously recalled items are used as cues. It is desirable to include rechecking in the simulated retrieval attempts because it ensures that the cues are used to their full potential (and rechecking will be useful in simulations to be reported later). When the LMAX parameter is set to 3 and a list length of 30 words is assumed (with 15 part-list cues), the cues (in the part-list cuing condition) are used for at least 45 (15 X 3) samples. It was felt that this cue-based sampling should not be interrupted with rechecking. Instead, the LMAX parameter was reduced to 1 and rechecking set to occur every 20 samples. Re-running the simulation program with these parameters produced the results shown in Figure 6. Changing these parameters erased the cross-over pattern that was seen previously such that the recall functions converge after approximately 100 samples but they do not cross. However, in order for the program to produce an inhibitory part-list cuing effect a stopping rule of less than 100 samples must again be assumed.

Using the assumptions of LMAX=1, rechecking every 20 samples, and a total of 60 samples a delayed part-list cuing experiment was simulated. Recall performance was simulated without cues, with immediate cues, and with cues delayed for 10 or 40 samples. The delayed cuing conditions were implemented by having the program perform normal free recall until the desired number of samples was reached. Then each of the part-list cues were used for sampling until the LMAX criterion was reached. Finally, if the maximum number of samples had not yet been reached then free recall would resume. The cumulative recall functions for this simulation are shown in Figure 7. The standard result of inhibition with immediate part-list cues was successfully simulated by the program. Further, part-list cues



<u>Figure</u> <u>6</u>. Simulation of target recall for Free Recall and Immediate Cues conditions as a function of the number of samples. (<u>LMAX</u>=1, rechecking after every 20 samples.)

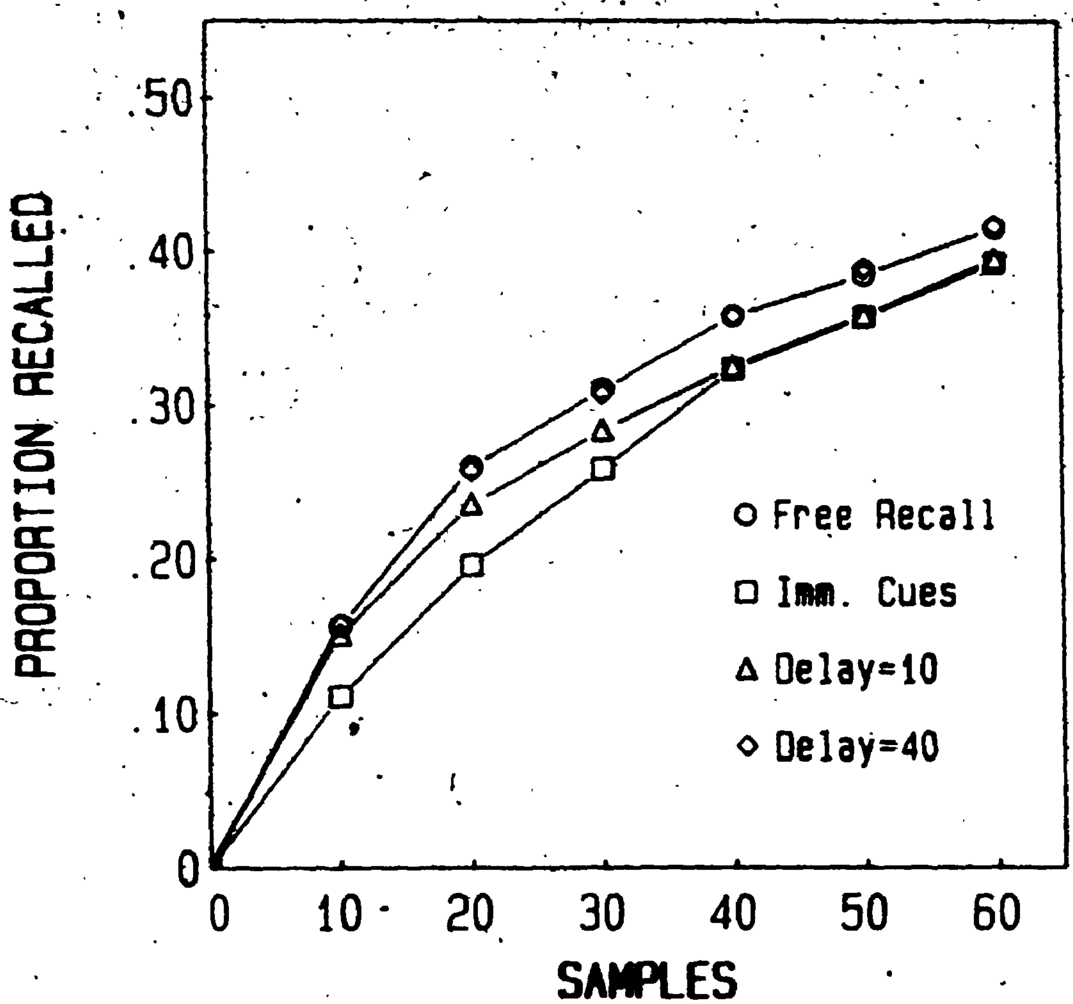


Figure 7. Simulation of a delayed cue experiment. (LMAX=1, rechecking after every 20 samples.)

introduced after 10 samples reduced recall performance to the level shown with immediate cues. Finally, cues introduced after 40 samples had little effect on recall performance.

These simulation results match the experimental results of Experiments 1 and 2 quite well. That is, cues introduced after short delays cause a sharp downward bend in the recall curves (as was seen in Experiment 1), while cues introduced after long delays have little effect (as was seen in Experiment 2). The major difference is that the simulations produce an inhibition effect that is considerably smaller than that found in Experiments 1 and 2 (2% versus 6% in the human data). It would be preferable if the magnitude of the effect could be correctly predicted, but the fact that the theory predicts any inhibition is an accomplishment. Perhaps changes in some of the parameters might allow the program to correctly simulate the size of the inhibition effect.

Therefore, if the number of samples is limited, the new SAM simulation program accurately models the effects of delayed part-list cues. The SAM theory can also provide a reasonable explanation for these effects. The delayed cues (like immediate cues) lead to a sampling bias that reduces the number of target items that are sampled and recalled. If the delay is long enough, however, the subjects will have sampled most of the target items that are accessible so the sampling bias will not be harmful. To explain the lack of facilitation with delayed cues it must be assumed that the subjects are gaining access to most of the items that are recallable so the delayed cues do not provide any advantage.

There is a contradiction between the present set of simulations and the simulation reported by Raaijmakers and Shiffrin (1981). The present research shows that delayed part-list cues have an inhibitory effect or no effect depending on the length of the delay. However, Raaijmakers and Shiffrin's simulation showed a positive effect of delayed part-list cues. One of the differences between these simulations is that the present program allows for rechecking during the retrieval attempt while the previous program did not. Perhaps this process of rechecking somehow changes the predictions of the SAM theory. A comparison of the data in Figures 4 and 5 shows that omitting rechecking from the simulations has some effect on the theoretical curves. With rechecking there is a slight cross-over of the free recall and immediate cues functions, but without rechecking the cross-over is much larger.

During rechecking each of the recalled items is used as a cue for the memory search. If rechecking occurs periodically during a retrieval attempt then there will be a mixture of context-based and context-plus-cue based sampling. Without rechecking, on the other hand, there will be little context-plus-cue sampling late in the retrieval attempt because few new items are recalled and used as cues. It is possible that the effects of delayed part-list cues will be affected by the presence of rechecking. If rechecking occurs periodically then context-plus-cue sampling is already being performed and the cues will not provide a large change in the search process. However, with no rechecking there will be little context-plus-cue sampling and the introduction of the delayed part-list cues will provide a dramatic change in the nature of the memory search. Thus, although there may be little effect of delayed part-list cues when rechecking is assumed, there may be a positive effect if no rechecking is assumed. This may explain why Raaijmakers and Shiffrin's simulation showed a positive effect of delayed part-list cues and the present simulations did not.

A third delayed part-list cuing experiment was performed to test the hypothesis that the presence or absence of rechecking will have an influence on memory retrieval performance. Raaijmakers and Shiffrin (1980) have suggested that verbal recall may represent a situation where little or no rechecking occurs. During verbal recall the subjects' responses are not visible so in order for the subjects to use the recalled items as cues they must be able to remember them. Since this memory for the recalled items may be poor, subjects who are responding verbally will have fewer cues available than subjects who write their responses. In the next experiment a verbal method of responding was used to determine if the effects of delayed part-list are sensitive to the presence of the previously recalled items.

EXPERIMENT 3

This experiment was an attempt to reconcile the results of the first two experiments and the simulation of delayed part-list cues reported by Raaijmakers and Shiffrin (1981). Experiments 1 and 2 showed that delayed part-list cues have an inhibitory effect or no effect depending on the length of the delay. Although a new version of the SAM simulation program was able to produce this pattern of results, the results are inconsistent with the original simulation of delayed part-list cuing reported by Raaijmakers and Shiffrin. It is possible that the process of "rechecking" is responsible for this inconsistency. Raaijmakers and Shiffrin did not include rechecking in their simulations, whereas the simulations reported here did include rechecking. Perhaps rechecking is important for determining the effects of delayed part-list cues.

Raaijmakers and Shiffrin (1980, pg. 235) suggest that verbal recall represents a situation where there is little or no rechecking during recall. With verbal recall subjects do not have their previous responses available on a recall page, and thus to use any of the recalled items as cues they must first be able to remember them. This may reduce the extent to which previously recalled items are used as cues. The purpose of this experiment was to determine if switching to a verbal method of responding will alter the effects of delayed part-list cues. If such an effect is found then the SAM simulation program can be applied to the delayed part-list cuing paradigm without the process of rechecking to determine if it produces the correct pattern of results.

Method

Subjects

One hundred and sixty-eight students (111 females) from the University of Western Ontario subject pool participated in the study. The subjects were tested individually in small computerized testing rooms. The subjects were randomly assigned to one of seven experimental conditions (24 subjects each).

Materials

The to-be-remembered words in this experiment were drawn from the Paivio et al. (1968) norms according to the criteria described in Experiment 2. Two lists of 32 words each and a practice list of 12 words were randomly drawn from the word pool. The lists were then randomly divided into equal subsets to provide cue and target items. The subjects were tested in two trials under the same testing conditions and the materials were counterbalanced such that, across 8 subjects, each list was used in each trial equally often, and each item was used both as a cue and a target during each trial. The counterbalancing order was replicated 3 times to give 24 subjects within each condition.

Presentation of materials and timing of the tasks was controlled by Apple IIe computers. These computers were equipped with analog switches so audio cassette recorders could be started and stopped whenever responses were required from the subjects.

Procedure

The experiment was completely automated but the subjects were given the opportunity to halt the procedure and consult with the experimenter if they desired. During the study phase of each trial the to-be-remembered words were presented on the computer screens for 2 seconds each (.5 seconds between words). The subjects were instructed to remember the words as best they could. After the study phase the subjects did a distractor task of solving multiplication questions (using pencil and paper) for one minute. The tape recorders were then started and the subjects were instructed to recall the words from the list in any order they wished. Subjects in the Free Recall condition recalled without cues until a 5 minute time limit was reached. Subjects in the cued conditions were given the part-list cues after 0 seconds, 15 seconds, 30 seconds, 1 minute, 2 minutes , or 3 minutes. The subjects were instructed to first read all the cues out loud, and then to use them as "clues" to help their recall. Also, the subjects in the delayed cue conditions were encouraged to recall all the words they could before the cues were introduced.

The subjects did two study-test trials under the same recall conditions, but a new list of words was used for the second trial. To familiarize the subjects with the procedure they were first given a practice trial in which 12 words were presented for study, math questions were attempted for 1 minute, and then 2 minutes were allowed for recall. Subjects in the Free Recall condition were not cued during this practice trial, Immediate Cues subjects received 6 items as cues at the beginning of the recall period, and the Delayed Cue subjects received their cues after 30 seconds.

Results

The cued subjects took an average of 30 seconds to read the part-list cues aloud and begin or resume recalling. When the recall tapes were transcribed the timer was stopped during this period, so an average of 4.5 minutes was allowed for recall. To make the Free Recall condition equivalent only the first 4.5 minutes of recall were scored. There were very few items recalled in the final 30 seconds of the recall period.

When the tapes from the recall sessions were transcribed the coder made time marks after 15 seconds, 30 seconds, and every 30 seconds thereafter. This allowed recall performance to be traced very accurately during the retrieval attempt. The cumulative recall functions for this experiment are shown in Figure 8. It can be seen that the part-list cues that were presented immediately, after a 15 second delay, or after a 30 second delay resulted in reduced recall performance when compared to Free Recall. Further, the 1 minute Delay condition also showed some inhibition effect. These findings are consistent with Experiment 1. However, the recall functions for the 2 minute and 3 minute Delay subjects show a marked increase in recall when the cues were introduced, and this is inconsistent with the results of Experiment 2.

These results were first analyzed by a 7 X 10 X 2 ANOVA with Condition as a between-subjects factor and Time and Trial as within-subjects factors. This analysis revealed significant main effects for Condition, $F(6,161)=2.27$, $MSe=.292$, Time, $F(9,1449)=371.97$, $MSe=.006$, and Trial, $F(1,161)=40.78$, $MSe=.102$. The main effect of Trial shows that recall was better on the second trial (.39) than on the first trial (.32). There were also significant interactions of Condition X Time, $F(54,1449)=2.23$, $MSe=.006$, and Trial X Time, $F(9,1449)=23.98$, $MSe=.002$, but these are an artifact of the cumulative scoring method.

An ANOVA holding Time at 4.5 minutes (i.e., an analysis of the final recall levels) revealed significant simple main effects for Condition, $F(6,161)=2.56$, $MSe=.045$, and Trial, $F(1,161)=45.03$, $MSe=.014$. A test of the Condition means

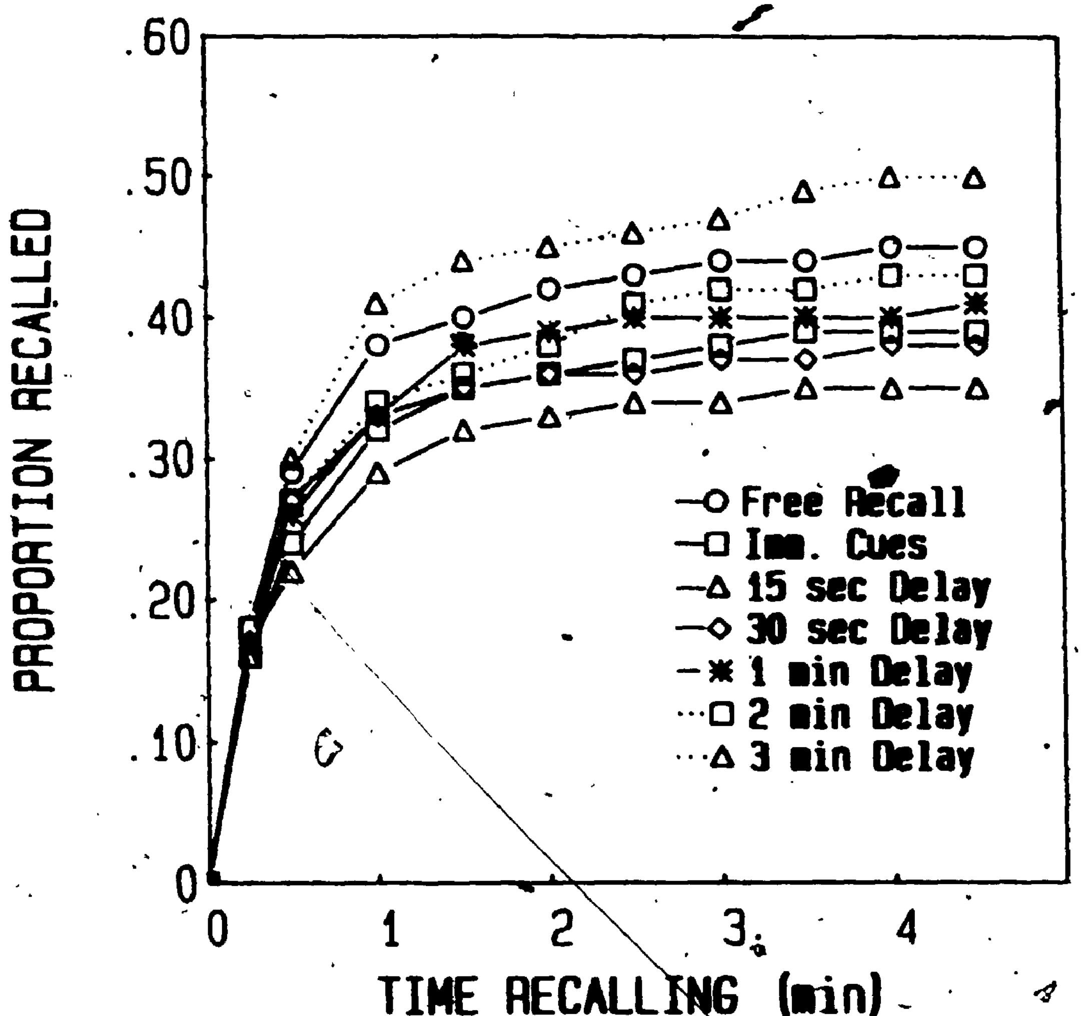


Figure 8. Experiment 3: Mean proportion of target words recalled in seven experimental conditions as a function of time spent recalling.

(using Tukey's HSD procedure) at 4.5 minutes revealed that the only significant difference was between the 3 minute Delay and 15 second Delay subjects. Thus, again the standard comparison of Free Recall versus Immediate Cues did not reach significance, although there is a definite trend for an inhibition effect (approximately 6%). An analysis of Condition after 3 minutes of recall revealed no significant differences between the conditions, $F(6,161)=2.00$. Finally, an analysis after 2 minutes of recall again showed significant differences between the Condition means, $F(6,161)=2.17$, $MSe=.038$, and this difference could be attributed to the difference between the 3 minute Delay and 15 second Delay conditions.

In order to analyze the apparent increase in recall performance shown by the 2 minute and 3 minute Delay groups, a difference score was calculated by subtracting the recall score after 3 minutes from the final recall performance (after 4.5 minutes). This score reflects the number of words recalled in the last 1.5 minutes of the retrieval attempt. An ANOVA with Condition and Trial as the factors revealed a significant main effect of Condition, $F(6,161)=3.80$, $MSe=.001$, and the means are given in the top row of Table 1. A post-hoc test of the Condition means showed that the difference scores for the 3 minute Delay subjects were larger than all the other conditions, which did not differ from one another. In contrast, an analysis of the recall curves for the 1.5 minutes before the cues

TABLE 1

Experiment 3: Mean proportion of target words recalled in the last 1.5 and 2.5 minutes of the recall period as a function of experimental condition.

	Condition						
Period	Free Recall	Imm. Cues	.25m Delay	.5m Delay	1m Delay	2m Delay	3m Delay
1.5 min	.0104	.0065	.0091	.0117	.0052	.0117	.0352
2.5 min	.0247	.0247	.0260	.0182	.0156	.0469	.0495

were introduced (recall after 3 minutes minus recall after 1.5 minutes) showed no significant differences between the conditions, $F(6,61)=1.64$, $p=.14$. Also, an analysis of the apparent divergence of the curves in the period from .5 minutes to 1.5 minutes also showed no significant effect of Condition, $F(6,161)=1.31$, $p=.25$. Thus, the increase in recall performance shown by the 3 minute Delay subjects was reliable.

A similar analysis was performed to examine the last 2.5 minutes of the recall attempt (the scores after 2 minutes subtracted from the final scores) and the means for each condition are shown in the bottom row of Table 1. An ANOVA again showed a significant effect of Condition, $F(6,161)=2.26$, $MSe=.003$, but none of the differences between the means were large enough for significance using Tukey's procedure. It is clear, though, that the means for the 2 minute and 3 minute delay conditions are higher than the other conditions. However, it must be concluded that only the 3 minute Delay group showed a significant facilitative effect of delayed part-list cues.

Discussion

There was some indication in this experiment that part-list cues that were introduced immediately, after 15 seconds, or after 30 seconds reduced recall in comparison to free recall, although the differences in recall performance were quite small (and not significant). Further, cues that were introduced after 1 minute had a slight negative effect. Thus, the results of Experiments 1 and 2 were replicated for the most part. The surprising (and reliable) result from this experiment was that cues introduced after a 3 minute delay resulted in an <u>increase</u> in recall performance.

In Experiment 2 cues that were introduced after 4 minutes had no effect on recall performance, whereas in this experiment cues introduced after 3 minutes had a positive effect. In both cases the recall functions were near asymptote when the cues were introduced so the results should be comparable. The difference between the two experiments was the form of responding. In Experiment 2 the subjects wrote their responses on sheets of paper while in this experiment the subjects spoke their responses. Thus, it appears that the method of responding is important for determining the nature of delayed cuing effects.

In the SAM theory the process of "rechecking" can be used to model the different forms of responding. During rechecking the computer simulation uses each of the recalled items as a cue for context-plus-cue sampling. This ensures that both context and context-plus-cues are used for sampling late in the retrieval attempt, and this should help recall performance. Perhaps when subjects are not able to view their previous responses (verbal recall) they are not able to do this rechecking. In the next section the SAM simulation program will be applied to the delayed part-list cuing procedure without the process of rechecking to determine if it can correctly simulate the effects of delayed cues under these conditions.

SAM Simulations of Delayed Part-List Cuing and Verbal Responding

To test whether the absence of rechecking can account for the different effect of delayed cues with verbal responding the simulation program was re-run without the rechecking process. The results of this simulation are shown in Figure 9. It can be seen that cues delayed for 10 samples tended to inhibit recall performance, while cues delayed for 40 samples had little effect (there is actually a slight positive effect, but the post-cuing increase in recall in the simulations is only 0.7%, while it was 3-4% in Experiment 3). Thus, the theory is not able to correctly simulate a positive effect of part-list cues that are delayed for long periods under conditions of verbal responding.

It might be possible for the simulation to produce the correct recall functions if more samples are allowed. In Figure 10 the recall functions for free recall, immediate cues, and a delay of 110 samples are traced for a total of 200 samples. Here there is a cross-over of the free recall and immediate cues functions: the inhibitory part-list cuing effect is only seen for the first 60 samples. Further, cues introduced after 110 samples failed to have an

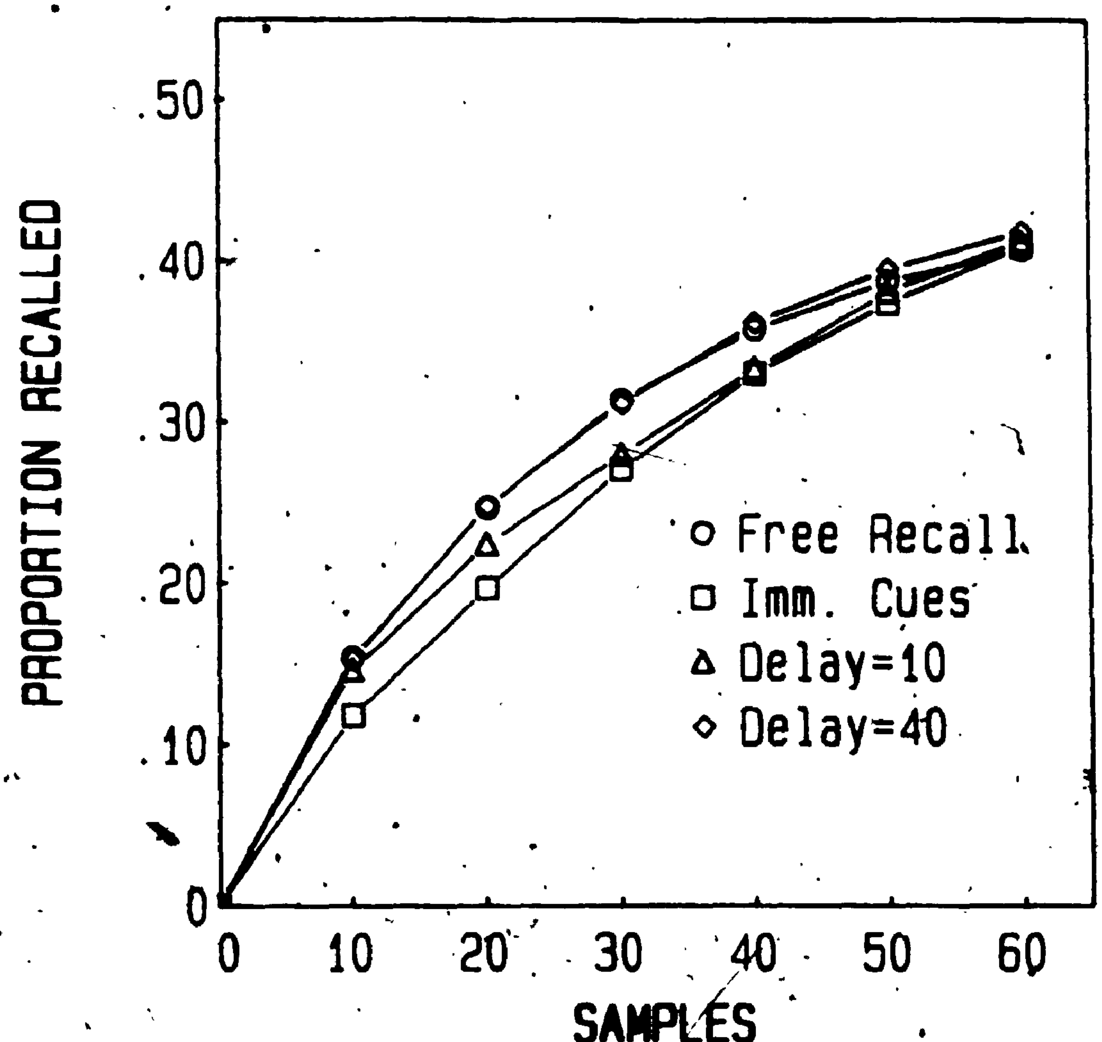


Figure 9. Simulation of a delayed cue experiment. (LMAX=1, no rechecking.)

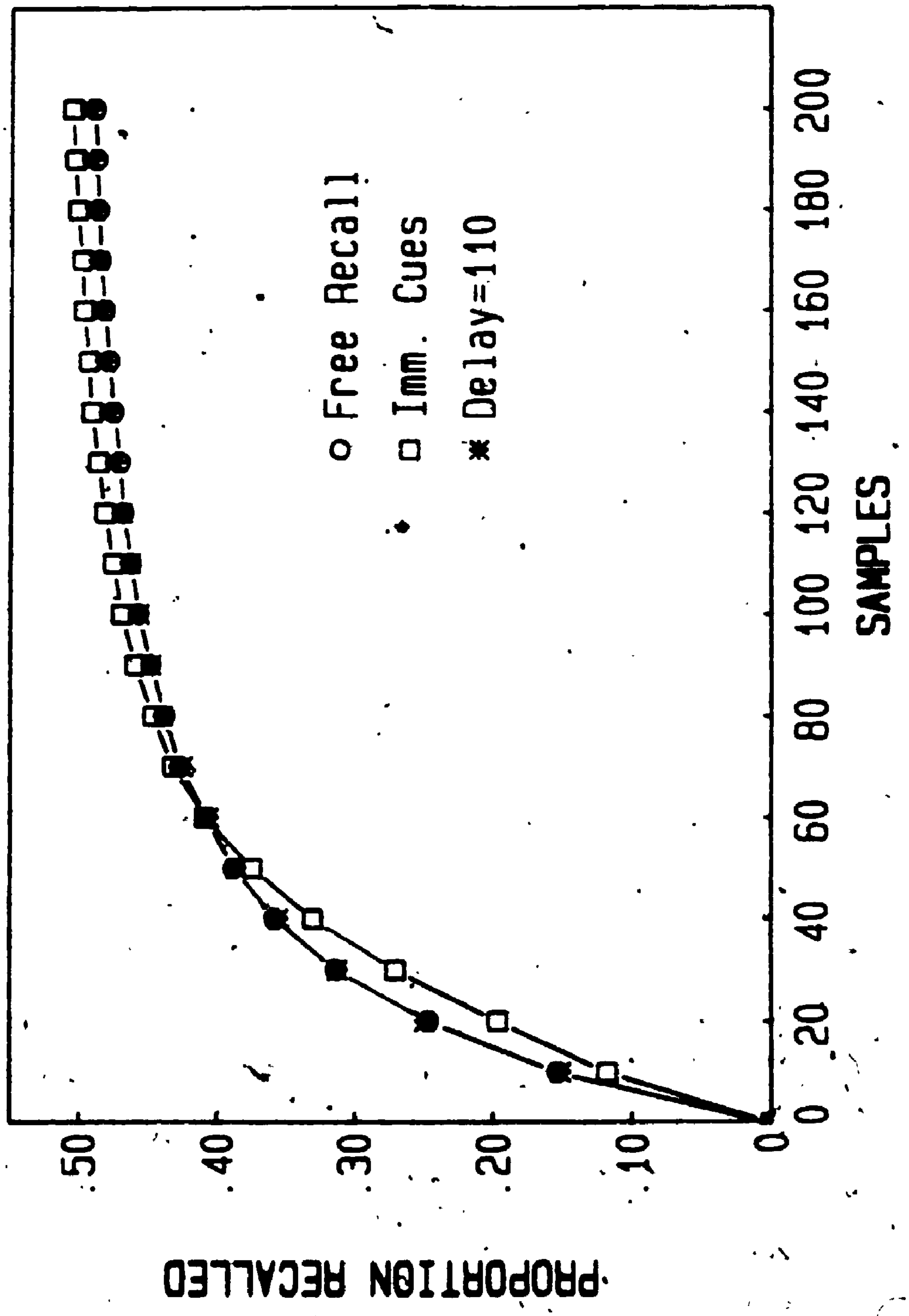


Figure 10. Simulation of a delayed cue experiment. The Free Recall and Immediate Cues functions are repeated from Figure 9. (LMAX=1, no rechecking.)

effect. Thus, the program is not able to simulate increases in recall with long-delay cues and verbal responding.

The results of this third experiment have shown that changing the method of recall to verbal responding does change the effects of delayed part-list cues. With written recall the effect of delayed cues is inhibitory or negligible for short and long delays respectively. Only under conditions of verbal responding and long delays is there a positive effect of part-list cues. The SAM simulation program is not able to predict this positive effect but the program does predict some effect of the method of responding (the presence or absence of rechecking). A comparison of Figures 4 and 5 shows that the cross-over of the free recall and immediate cues curves is much more pronounced if rechecking is eliminated from the simulations. Thus, the SAM theory does predict some effects due to the nature of responding, but it does not produce the results found in Experiment 3.

In general, the simulated data from the SAM theory show very small inhibition effects (2% compared to the 6-10% seen in Experiments 1, 2 & 3 and reported in the literature). Perhaps larger effects and better predictions would be produced with different parameter values. However, Raaijmakers and Shiffrin argue that the SAM program should be applicable to a variety of situations without major changes in the parameters. Further, if too many parameters are allowed to vary then any explanations that the theory provides will not be very satisfactory. As a check, however, the simulations reported here were also run using a set of parameters suggested by Gillund and Shiffrin (1984). These parameters were: a=.25, b=.20, c=.15, d=.075, e=f=g=0. The same pattern of results shown in Figures 9 and 10 was produced with these parameter values, and the part-list inhibition effect after 60 samples was only 1.92%.

In summary, the SAM simulation program is able to model most of the recall functions found in Experiments 1, 2, and 3. The problematic finding is that there was no evidence of a cross-over of the free recall and immediate cues functions in any of the experiments (or the literature), and yet the theory consistently predicts such a cross-over. To avoid this cross-over it must be assumed that the subjects sample less than 60 times. With this assumption the theory is able to model all of the effects of delayed part-list cues, except long delay conditions with verbal responding. Further, it cannot model the asymptotic recall values seen in the empirical data. Thus, the theory must be corrected such that it either produces the correct asymptotic recall curves or includes a principled method of terminating a recall attempt.

EXPERIMENT 4

The final experiment was designed to test the sampling rule of the SAM theory. In the theory items are stored in memory with different strengths of representation. Since a ratio rule determines what is sampled, items are in competition such that stronger items in memory will tend to be recalled at the expense of weaker items. While Raaijmakers and Shiffrin do not rely on this mechanism to explain the part-list cuing effect, they do use it to explain output interference. When items are recalled it is assumed that their strengths are increased and this will tend to block recall of weaker items.

Due the the complicated nature of the the SAM theory (and the program), it is difficult to predict how much blocking will be produced by the ratio rule. Further, there has been little effort devoted to testing this aspect of the SAM theory, even though a ratio rule is used in a variety of memory theories (e.g., Rundus, 1973; Anderson, 1983). In the present experiment a new paradigm was developed to determine to what extent strong items will block the recall of weak items. The SAM simulation program can then be adapted to the new situation to determine if it correctly simulates the blocking effects.

The concept of "strength" is used extensively in memory research, although it is not clearly defined. Many memory theories propose a single trace for each item in memory.

In this view, each time an item is encountered some kind of strength counter is increased. Others have suggested that each experience of an item leads to a new memory trace and, thus, frequently presented items are stronger because they are represented more often in memory. Another approach is to describe strengthening as an elaboration of a memory trace such that it becomes associated with other items in memory. Each of these descriptions of memory strength has led to different experimental paradigms. In all cases the concept of strength has been operationalized as some manipulation that affects the probability of items being recalled. Thus, strength has been operationalized as the familiarity of an item, the number of presentations during an experiment, or the level of processing used during encoding (to name only a few).

The SAM theory remains neutral on the issue of how to describe memory strength. Raaijmakers and Shiffrin (1981) make a distinction between storage structures and retrieval structures. A retrieval structure represents the probability of retrieving each item given a set of memory probes or cues. A storage structure represents the information that is stored in memory. Thus, a retrieval structure is an operationalization of a storage structure, and many storage structures could lead to the same retrieval structure. Therefore, strength is operationally defined in the SAM theory as the probability of retrieval given certain cues. The basis for this strength is left open so the theory can be applied to a variety of situations. The ratio rule for sampling in the SAM theory determines how the strengths in memory will affect remembering. The ratio rule operates in the same manner for any type of strength.

Although the ratio rule for sampling has a lot of intuitive appeal, there is some evidence that is inconsistent with the rule. First, part-list cuing effects are evident in initial recall trials but the effects dissipate in final free recall (FFR) trials even though the cues show strengthening (as shown by increased recall performance; Basden et al., 1977, Expt. 2). If strong items in memory can block the recall of weaker ones then one would expect that the strong cues would block the recall of the targets in the FFR test, and this did not occur.

Also, retrieval can be independent of the strength of the items in memory. Using a paradigm in which only free recall was tested, Basden et al. (1977, Exp. 1) demonstrated this independence by preparing word lists in which target words were combined with strong or weak "filler" words. They did this by gathering categorized lists in which the frequency of the instances within the categories was varied. They argued that frequent or dominant category instances (as defined by the Battig and Montague, 1969, norms) should have stronger representations after the learning phase of the experiment than less frequent instances. The critical comparison was when low frequency instances were combined in the same list with either other low frequency instances, or high frequency instances. If the strength of items in memory is important then the high frequency items should block the recall of the low frequency items. However, no difference in recall of the low frequency items was found.

This suggests that the ratio rule may not be correct, although one could argue that the frequency manipulation was not sufficient to produce large differences in representation strength. Basden et al. (1977) argue that strength can be operationalized by the normative dominance of an item within a category. However, it could be that the dominant items differ from non-dominant ones by factors other than strength. For example, dominant category members may be more concrete or more frequent in the English language. This could produce differences in recall levels that we might not want to attribute to representation strength.

An alternative way to operationalize strength is to manipulate the number of times an item is presented during study. If multiple presentations lead to stronger memory representations then this should block the recall of once-presented items within the same list. Tulving and Hastie (1972) had subjects study a list of random words in which some items were presented once and some items were presented twice. This was compared to a condition where all the words were only presented once. Recall was tested under "free recall" conditions and the once-presented words were recalled to a lesser degree when studied in the presence of twice-presented words than in the presence of other once-presented words (29% versus 39%). This would suggest that strong items in memory can block the retrieval of weak items.

However, a follow-up study by Hastie (1975) showed that the blocking effect might be due to a peculiarity of the procedure. Tulving and Hastie asked their subjects to recall the twice-presented words by writing them down twice and to record the once-presented words only once. Thus, the subjects had to remember both the list items and their frequency of occurrence. Hastie (1975) found that if the recording requirement was not part of the experiment then the blocking effect disappeared. This would suggest that it was the added load of remembering and recording frequency information and not the strength of the items that produced the blocking effect reported by Tulving and Hastie (1972).

To further confuse the matter, there is another study which contradicts this latter conclusion. Roediger et al. (1977) had subjects study a list of words (twice) and then study a set of part-list cues. The cues were then removed and the subjects were asked to recall all the list items, including the cues. The subjects were not required to mark the thrice-presented items (the cues) in any way so the experiment was essentially a free recall experiment. This procedure increased the strength of the thrice-presented items (higher recall performance) and there was a small but significant inhibition effect when compared to [illegible]

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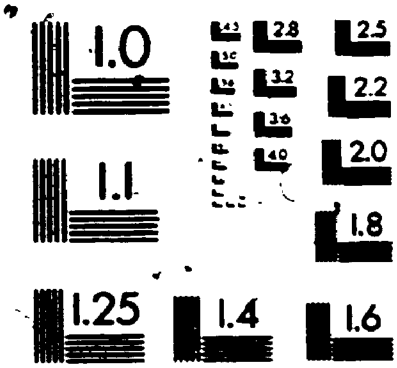


condition in which all the items were presented twice. However, this inhibition was smaller than that found with the standard part-list cuing conditions in which the cues remain in view during their retrieval attempt. This suggests that strong items may block the recall of weak items, but the part-list cuing effect may not be completely explained by this blockage.

In summary, it is not clear whether strong items in memory will block the recall of weaker ones. Basden et al. manipulated the type of materials and found no blocking, Tulving and Hastie found blocking with twice-presented items, but Hastie later showed that this was due to a peculiarity in the testing procedure. However, Roediger et al. removed this peculiarity and found some blocking.

The present study was designed to clarify this issue. In designing the study it was clear that a manipulation of the types of materials was not satisfactory because it is difficult to control the factors that affect recall. Further, comparing recall in the presence of once versus twice-presented items is not satisfactory because even if the subjects are instructed not to record the frequency of presentation, they may do so on their own.

In this study all the subjects were given lists to remember in which some items were presented once and some presented twice. Memory was assessed by a free recall test in which the subjects were instructed to recall all the words, regardless of the number of presentations. The important comparison is not between the presence and absence of twice-presented items, but between different "kinds" of twice presented items. Further, the manipulation of the twice-presented items was not in their inherent nature, but in the type of encoding that was used (the level of processing, cf. Craik & Lockhart, 1972). All the subjects studied a list of random words, and then studied half of the list a second time. The type of study for the second presentation of the twice-presented words was manipulated such that some subjects answered questions about the letters that made up the words, some answered questions about rhymes for the words, and some answered questions about the meanings of the words (a fourth group simply studied the words again).

Thus, strength is operationalized as the different levels of encoding used in the "levels of processing" paradigm. This manipulation is known to change the level of recall performance across a wide variety of conditions (e.g., Craik & Tulving, 1975). If this manipulation can be thought of as changing the relative strength of the items, then we can determine the extent to which strong items block the recall of weaker items.

Method

Subjects

Sixty-four students (37 males) from the University of Western Ontario subject pool participated in this study. They were tested in small groups of 1 to 4 people. The subjects were randomly assigned to one of 4 experimental conditions (16 subjects each) by a predetermined pattern.

Materials

A study list of 32 words was randomly selected from the Paivio, Yuille, and Madigan (1968) norms using the criteria described in Experiment 2. Six different levels-of-processing questions were developed for each of the words in the study list. Two of the questions asked about the letters that make up a word ("Does this word contain the letter 'R'?"), with one question requiring a "yes" answer and one requiring a "no" answer. Similarly, two questions asked about rhymes for the words, with the correct rhymes coming from a dictionary of English rhymes (Walker, 1983). Finally, two questions asked about the meaning of the words ("Is this a type of plant?"), and again there were questions requiring either a "yes" or "no" response.

The list of 32 words were divided into two sets of 16 words. The sets were counterbalanced such that each set was used as the once-presented and twice-presented items equally often. Further, the correct answers to the questions were "yes" or "no" 50% of the time. Thus, across 4 subjects each word was used as a once-presented and twice-presented item, and the questions on the second presentation required both a "yes" and a "no" response. This counterbalancing was replicated 4 times within each condition to give 16 subjects. Further, when the lists were presented for the level-of-processing questions there was a random sequence of "yes" and "no" questions.

Procedure

The presentation of materials and timing of this experiment was controlled by an Apple II computer. The list of words were first presented on a large computer screen at the front of the testing room and the subjects were instructed to remember the words. The words were presented for 2 seconds each, and there was a half-second pause between the words.

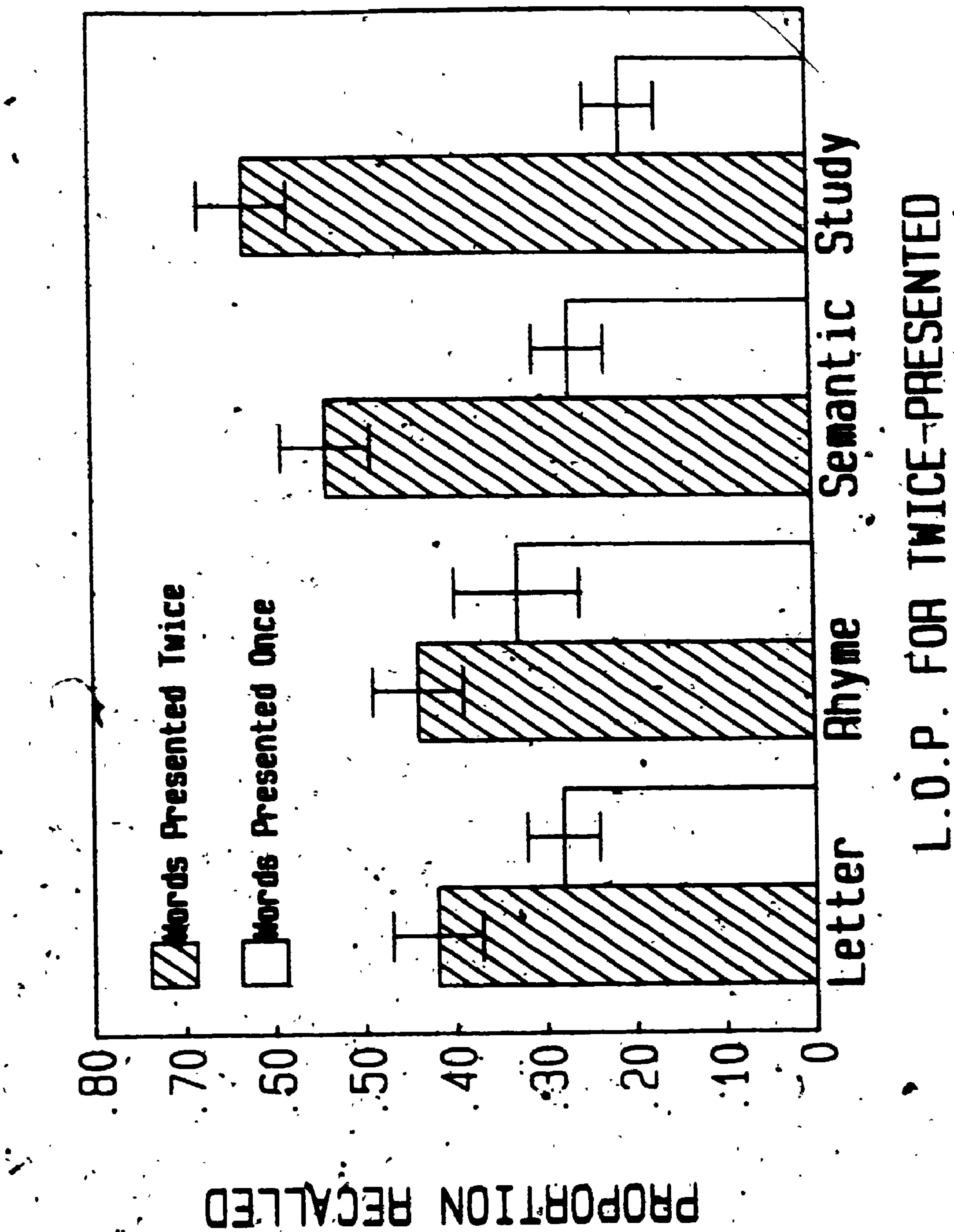
Following the initial presentation of the list the subjects did a distractor task of solving multiplication questions (random 2-digit numbers) for 1 minute. A subset of the list (16 words) was then presented for 5 seconds per word (1/2 second between words) and the subjects were informed that this was part of the list they had seen earlier. During this second presentation the subjects answered the level-of-processing questions that were appropriate for their condition (letter, rhyme, or semantic), or they simply studied the subset of 16 items a second time. Those who were answering questions were instructed to look at the word on the screen and then read the corresponding question in their booklet and circle the correct response. The computer generated a tone when each word was presented to signal the subjects.

After the second presentation of the words the subjects performed another distractor task in which they were asked to generate and write down the names of the states in the U.S.A. for 2 minutes. Finally, the subjects were asked to recall the list of words they had studied previously. The instructions emphasized that they were to recall the words they had seen on the computer monitor (in any order), regardless of whether the words were presented once or twice. Five minutes were given for this recall test.

Results

Although the levels of processing (LOP) manipulation was only applied to the twice-presented items, it was predicted that it would have an effect on the once-presented items. Thus, LOP was included as a main effect in the analysis even though it was not truly crossed with the other factor in the design. The results were analyzed by a mixed ANOVA with level-of-processing (4 levels, between subjects) and Presentation (once- versus twice-presented items, within subjects) as the factors. This analysis revealed a significant main effect of Presentation, $F(1,60)=108.91$, MSe=4.236, and a significant interaction of Presentation and LOP, $F(3,60)=9.92$, MSe=4.236. The main effect of LOP was far from significance ($F<1$). The nature of the interaction can be seen in Figure 11. The LOP of the twice-presented items had a large effect on the recall of those items, but only a small effect on the once-presented items. This was confirmed by an analysis of simple main effects which showed that the effect of LOP was significant for the twice-presented items, F([illegible],60)=3.64, MSe=10.560, but not significant for the once-presented items, $F(3,60)=1.10$, MSe=9.830, $p=.36$. A post-hoc comparison of the means (using Tukey's HSD procedure) for the twice-presented items revealed a significant difference between the Study and Letter conditions.

It is clear, then, that the level of processing of twice-presented items will influence the strength of these items. The usual pattern of results found with the LOP manipulation was obtained in this experiment (i.e., the "deeper" the level of processing the higher the recall performance). It is interesting to note that the "study" instructions produced the best recall performance. This may represent the "deepest" level of encoding, or encoding that is more appropriate for the test that follows. In any event, the important result is that a difference in recall performance for twice presented items was produced (the difference between the Letter and Study conditions is 21%).



<u>Figure 11</u>. Experiment 4: Mean proportion of words recalled as a function of number of p:esentations and level of processing for the second presentation.

These different levels of recall for the twice-presented items do not influence recall of once-presented items to a large degree (the maximum difference of 12% is between the Rhyme and Study conditions). Any increase in recall due to deeper levels of processing does not appear to be done at the expense of the once-presented words. However, the data in Figure 11 do suggest a slight trend for the once-presented items to have poorer recall with higher levels of processing for the twice-presented items. Perhaps a more sensitive analysis would show this trend. To explore this possibility correlational analyses were done in which the scores for each subject on once- and twice-presented items were compared. The data were collapsed across the groups so the effect of the actual number of twice-presented items recalled could be seen.

The first correlational analysis was a simple regression of once-presented scores on twice-presented scores. The resulting correlation was a significant +.45, and the equation for the best fit regression line was

$$\text{ONCE} = .41\ (\text{TWICE}) + 1.02.$$

This means that subjects with higher levels of recall for twice-presented items also have higher levels for once-presented items. This would suggest that greater strength for twice-presented items does not block recall of once-presented items.

The correlational data indicate that the slope of the regression function (.41) is less than 1, which means that higher levels of recall for twice-presented items are not matched completely by recall of once-presented items. In fact, for each increase in twice-presented recall of one word there is a corresponding increase in once-presented recall of less than 1/2 of a word. Perhaps higher levels of recall for twice-presented items are blocking increases in recall of once-presented items. To explore this possibility a new score was developed to express the proportion of the total number of words recalled that is represented by the once-presented items. This new score was defined as

$$\text{PROPORTION} = \frac{\text{ONCE}}{\text{ONCE} + \text{TWICE}}$$

and was calculated for each subject. A regression analysis was then performed in which the proportion was regressed on the recall of twice-presented items. If the strength of twice-presented items can block the recall of once-presented items then there should be a negative correlation. The actual correlation was a nonsignificant -.15, and the regression equation was

$$\text{PROPORTION} = -.007\ (\text{TWICE}) + .381.$$

The nonsignificant correlation and the near-zero slope of the regression line show that once-presented items make up a fairly constant portion of the amount recalled across all levels of twice-presented recall. In fact, the average is 33% of the total recall.

A similar analysis was conducted using a ratio of the once and twice scores as a dependent variable. This score was defined as

$$\text{RATIO} = \frac{\text{ONCE}}{\text{TWICE}}$$

and a regression of this ratio score on the recall performance of the twice-presented items revealed a nonsignificant correlation of -.1969 ($p = .12$). The regression equation for this dependent variable was

$$\text{RATIO} = -.0206\ \text{TWICE} + .72959.$$

Thus, the ratio of once- and twice-presented items is relatively constant across all levels of twice-presented recall.

Thus, in each of four analyses the different levels of processing for twice-presented items has only a slight effect on the recall performance for once-presented items.

Discussion

This experiment tested the sampling rule of the SAM theory. The level of processing of twice-presented items was manipulated using a levels-of-processing encoding task. This resulted in different levels of recall, and presumably different strengths of representation. These different strengths had only a small (nonsignificant) influence on the level of recall of once-presented items. It seems clear, then, that any blocking effect produced by strong items in memory is quite small at best.

These results are consistent with the findings presented by Basden et al. (1977), while not relying on inherent differences in the materials. The results are inconsistent with Roediger et al.'s (1977) findings that presenting part-list cues after a list is studied and then removing them before the recall test acts to increase recall of the cues and decrease the recall of target words (to some extent). However, Roediger et al. point out that the subjects may actually place themselves in a situation that is close to the usual part-list cuing paradigm. A fine-grain analysis of the recall protocols showed that the subjects tended to recall the cue words first before they recalled any of the target words. Perhaps the subjects were cuing themselves to some extent, and thus succumbing to the part-list cuing effect. The present study differed from the Roediger et al. study in that the twice-presented items were not presented as "clues" in this study, whereas Roediger et al. encouraged the subjects to use the cues to aid their recall. It is probably necessary for the subjects to attempt to use the cues as "clues" to produce the part-list cuing effect.

The present results may be problematic for the SAM theory of retrieval. The theory predicts that strong items in memory should block the recall of weaker ones due to the ratio rule that is used for sampling. However, it is difficult to determine how much of a blocking effect the SAM theory predicts. The findings of the present study suggest that the blocking effect should be quite small. In the next section a set of simulations are reported to determine if the SAM theory can predict the small blocking effect seen in the present findings.

SAM Simulations of Item Strength Manipulations

The nature of the ratio rule in the SAM theory means that strong items in memory will tend to block the recall of weak ones. The general rule is:

$$P(s) = \frac{S_i}{\sum S_i}$$

where P(s) is the probability of sampling a particular item, and S is item strength. Due to the ratio format, any increases in the strengths of the other items (the denominator) will decrease the probability of sampling a particular item. However, in Experiment 4 it was found that strong items in memory do not have a large blocking effect on the recall of weaker ones. This section will determine if the SAM program can correctly simulate these results.

The assumptions used for these simulations were those developed for the simulations of delayed part-list cues: a=.1, b=.1, c=.1, d=.01, e=f=g=0, LMAX=1. The list length was assumed to be 30 words. A total of 60 samples was assumed, with rechecking occuring every 20 samples. As was done previously, 500 simulated subjects were run and the results were averaged.

The SAM theory has never been applied to the levels-of-processing paradigm. Thus, the first step in the current simulations was to implement the level of processing manipulation using reasonable assumptions. There are two possible effects of "deeper" levels of encoding, stronger context-to-item associations or stronger inter-item associations. Since the items are studied in isolation in this paradigm it would seem that the context-to-item associations would be most important, but one does not want to rule out inter-item strengthening completely. Thus, in the present simulations both context-to-item and inter-item strenghtening were examined.

Two new parameters were introduced to implement the increases in item strength. <u>CINC</u> was defined as the context-to-item strengthening, and <u>IINC</u> was defined as the inter-item and self strengthening. These strengthening parameters operate in a multiplicative fashion such that the appropriate strengths in the storage matrices are multiplied by the value of the parameter (thus, a value of 1.0 means no strengthening). In order to simulate the conditions of Experiment 4 the simulation program was altered such that after the storage matrices had been created (i.e., after the initial learning), a subset of 15 items (the twice-presented items) were randomly selected for strengthening. The strengths in the matrices for these items were then multiplied by the value of the appropriate parameter. It was assumed that no strengthening occurred for items that only had residual strengths. Thus, no new associations were formed during this strengthening procedure, but some of the existing ones were strengthened.

Once the subset of items was strengthened, normal free recall was simulated. As usual, sampling was initially based on context alone but any recalled items were used for context-plus-cue sampling. Forty-nine simulation runs were performed to examine 7 values (1.0, 1.5, 2.0 ... 4.0) of the CINC parameter (the context-to-item strengthening) in combination with 7 values of the IINC parameter (the inter-item strenghtening). The results for the different values of IINC when CINC is held at 1.0 are shown in Figure 12. It can be seen that the IINC parameter is not successful in producing an advantage for the strengthened items. This suggests that inter-item strengthening does not have a large influence on recall performance in this situation.

The results for the different values of CINC when IINC is held at 1.0 are shown in Figure 13. Here there is a difference between strengthened and not-strengthened items. Thus, context-to-item strengthening does have a large effect on recall in this situation. The data also show that strengthening leads to an increase in recall of 29% for the strengthened items, and a decrease of 10% for the items not strengthened. This corresponds quite well with the results of Experiment 4 where the different levels of processing lead to an increase in recall of 21% for the twice-presented

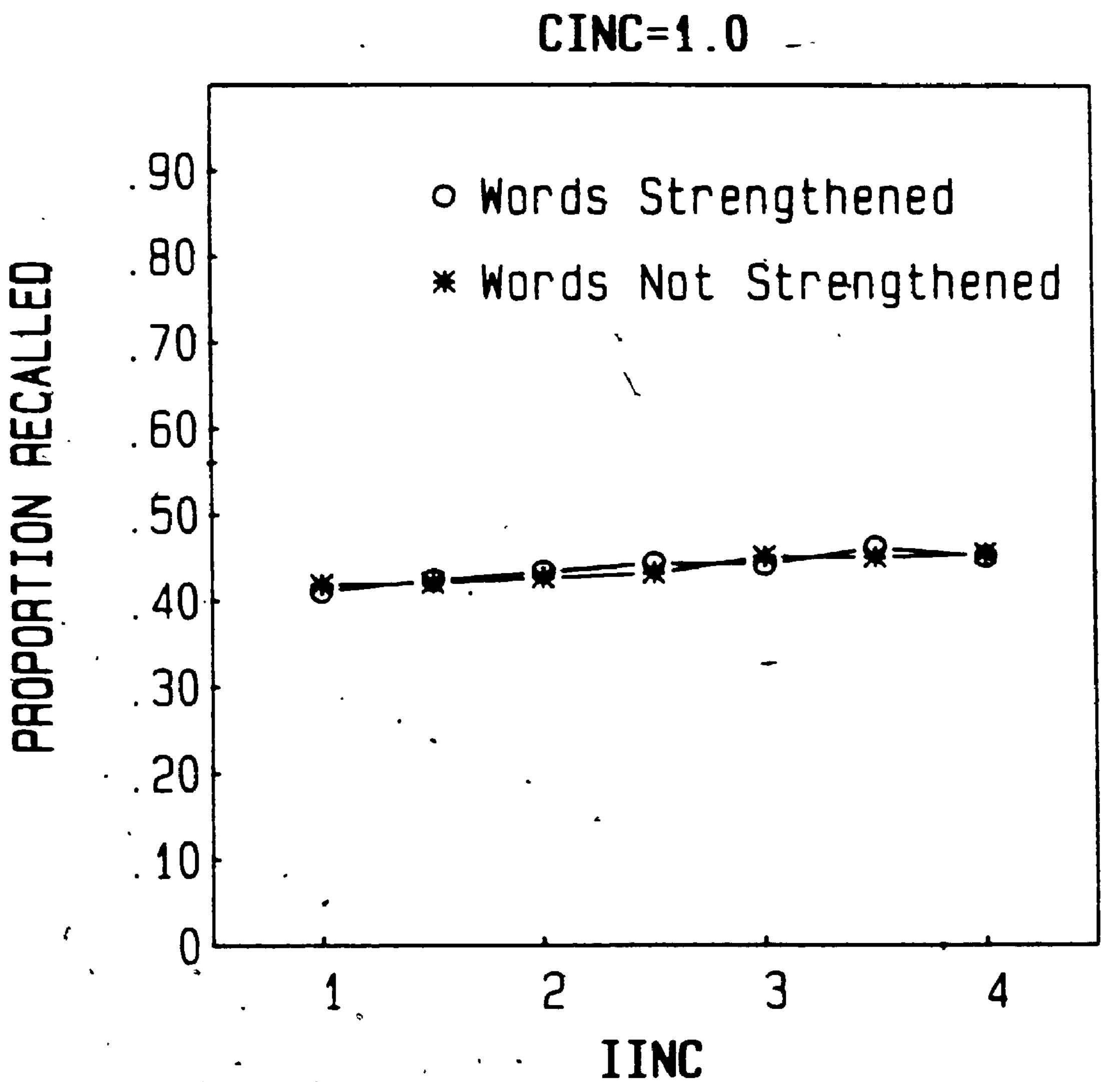


Figure 12. Simulation of recall for words that are strengthened and not strengthened as a function of inter-item strengthening (*IINC*). The context-to-item strengthening (*CINC*) is held at 1.0.

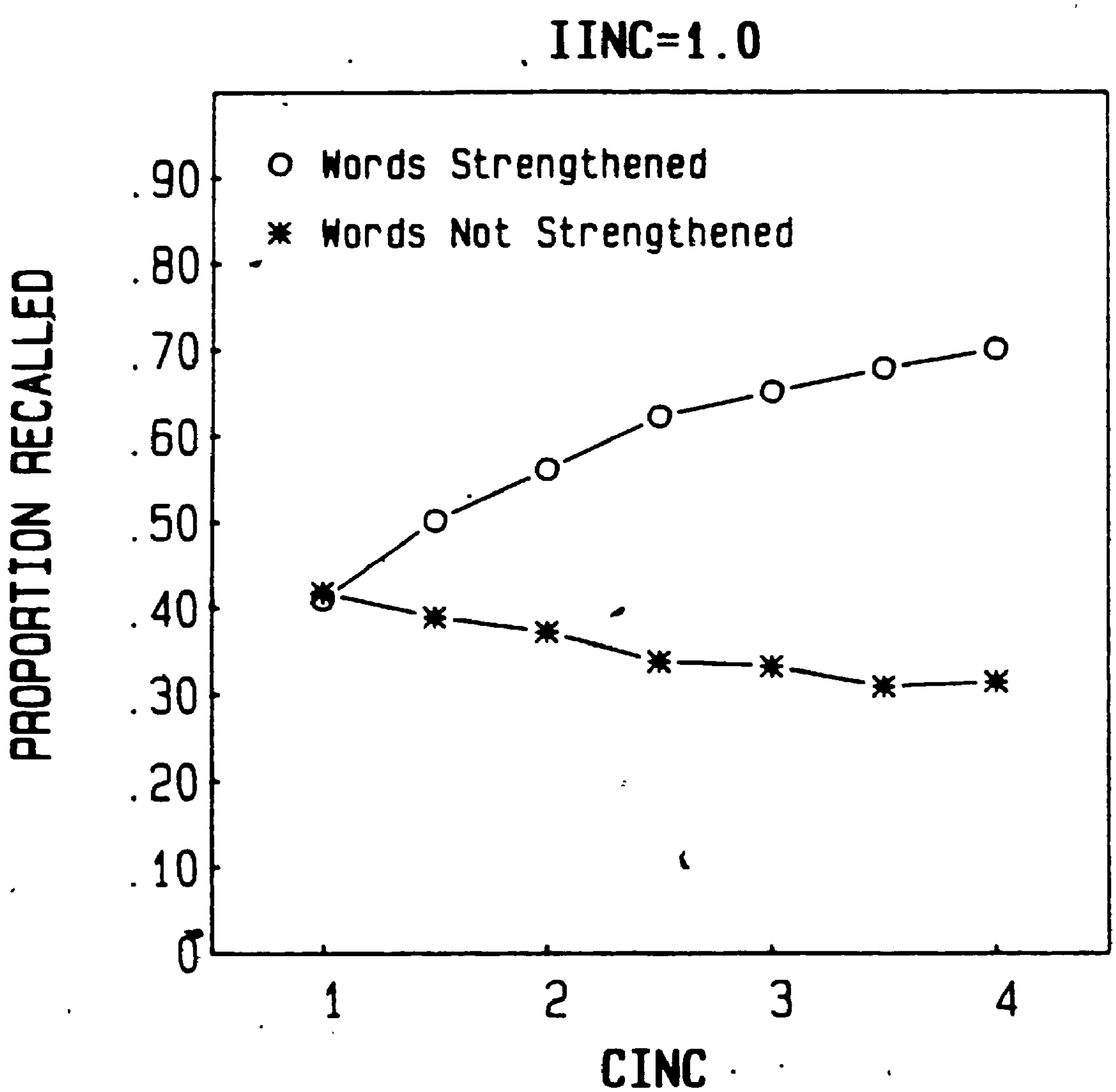


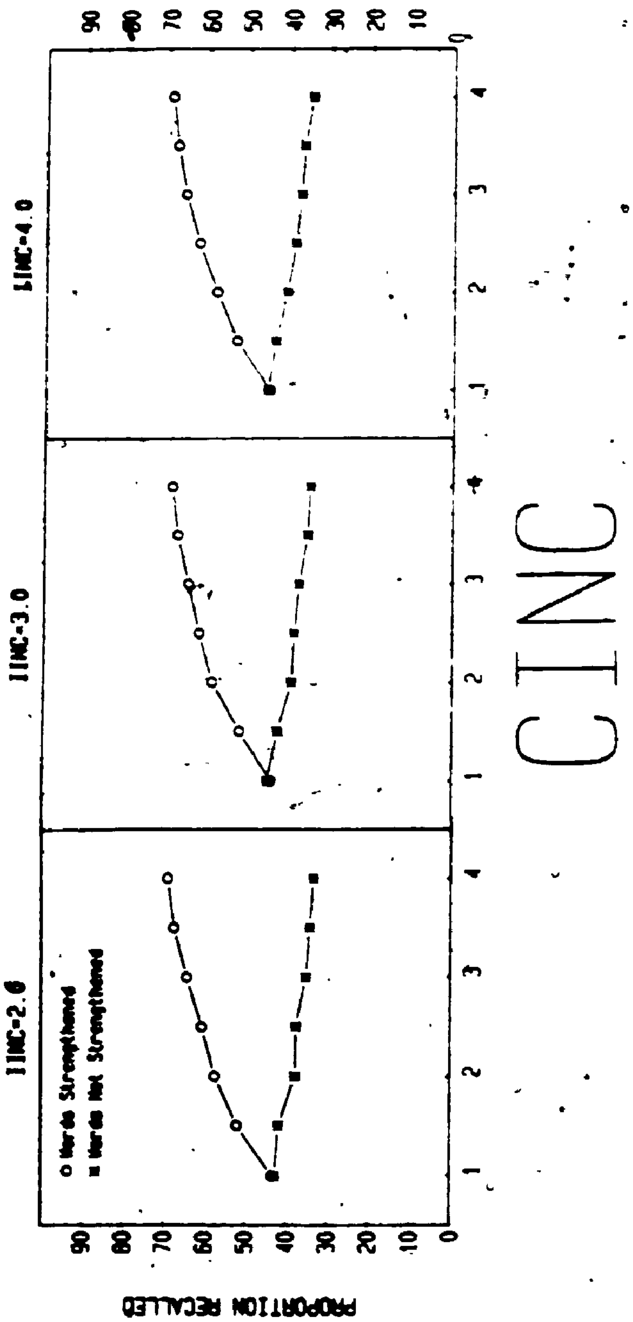
Figure 13. Simulation of recall for words that are strengthened and not strengthened as a function of context-to-item strengthening (CINC). The inter-item strengthening (IINC) is held at 1.0.

items and a decrease of 12% for the once-presented items.

To test for interactions between the two strengthening parameters the results for the different values of CINC when IINC is held at 1.0, 2.0, and 4.0 are shown in Figure 14. It can be seen that the same pattern of results emerges regardless of the value of IINC. The only effect of IINC is to increase (slightly) the overall level of recall performance.

The simulations of delayed part-list cuing showed that the predictions of the SAM theory differ depending on the number of samples that are assumed. To test for this same result in the current situation the recall scores for the once-presented items were calculated in a cumulative fashion over 400 samples with CINC (context-to-item strengthening) set equal to 2.0, 3.0, or 4.0 (IINC=1.0). The results of this analysis are shown in Figure 15. It can be seen that as CINC increases there is a decrement in recall, and this decrement is fairly constant throughout the retrieval attempt. Figure 16 shows the results if a total of 400 samples is assumed. Here the strengthened items show an increase of 24% while the not-strengthened items show a decrease of 6%. The decrease in the not-strengthened items is less than the results of Experiment 4 (12%), but the SAM theory is correct in predicting a slight blocking effect.

Therefore, the competition action of items in memory is not as powerful as the ratio rule suggests it might be. This suggests that strength competition may not play as



<u>Figure 14</u>. Simulation of recall for words that are strengthened and not strengthened as a function of context-to-item strengthening (<u>CINC</u>) when the inter-item strengthening (<u>IINC</u>) is held at 2.0, 3.0, or 4.0.

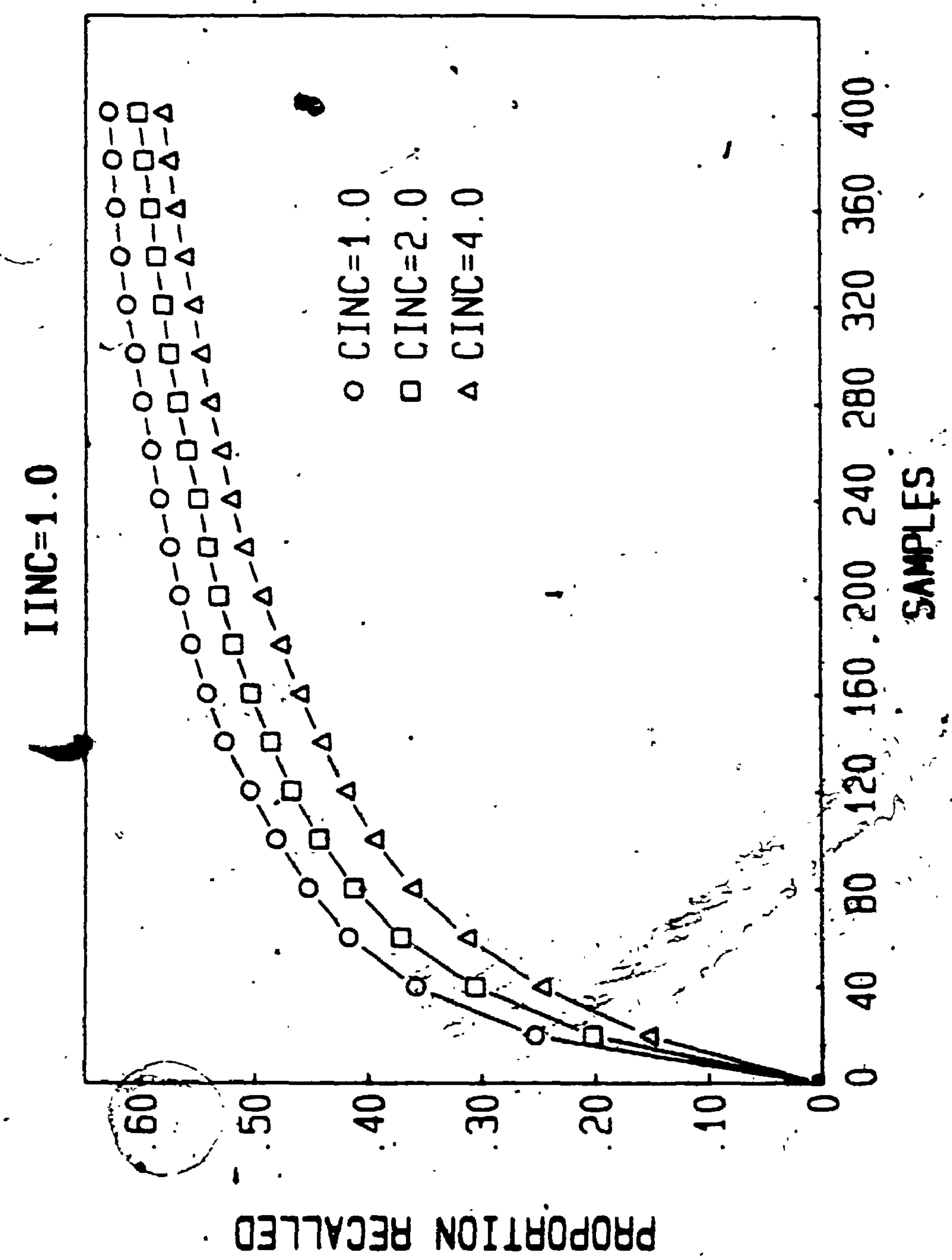


Figure 15. Simulation of recall for words not strengthened when the context-to-item strengthening (CINC) is set at 1.0, 2.0, or 4.0 as a function of the number of samples. The inter-item strengthening (IINC) is held at 1.0.

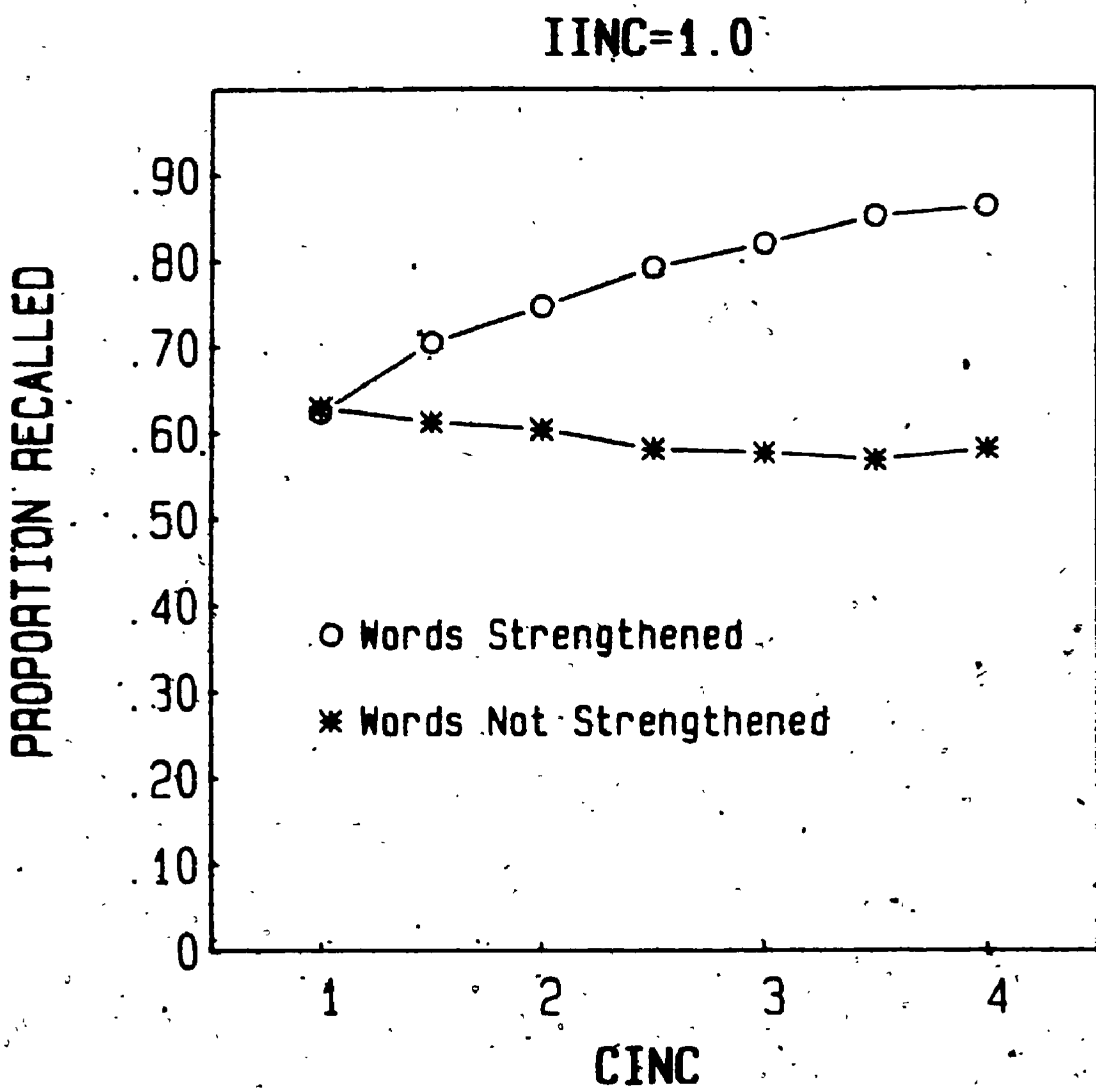


Figure 16. Simulation of recall for words that are strengthened and not strengthened as a function of context-to-item strengthening (CINC). The inter-item strengthening (IINC) is held at 1.0. The number of samples is set to 400.

important a role as some theorists (e.g., Anderson, 1983; Rundus, 1973) have suggested. Nevertheless, the SAM program is able to correctly simulate the slight blocking effects that are produced. Thus, the SAM theory has been applied to a new situation with little change, and it has fared very well.

GENERAL DISCUSSION

The goal of this research was to expand our knowledge of human memory. In particular, the research focused on theoretical proposals for memory storage and retrieval. Past research has shown that related information presented during the act of remembering sometimes hinders recall performance (retrieval inhibition). An example of this inhibition is the surprising effect of part-list cues: they either fail to facilitate recall or inhibit recall slightly. While most memory theories have trouble accounting for these results, Raaijmakers and Shiffrin (1980, 1981) have recently described a theory (SAM) which seems to provide an explanation. In this thesis two new experimental paradigms were developed (delayed part-list cues and manipulations of item strength) and the SAM theory was extended to these situations and evaluated.

Delayed Part-List Cues

Raaijmakers and Shiffrin (1981) reported a simulation which showed that delayed part-list cues will facilitate recall, an effect opposite to that found with immediate cues. However, the experimental evidence they used to support this prediction is problematic and the assumptions used in the simulation may not have been appropriate. Thus, a series of experiments was performed to determine the true effect of delayed part-list cues, and the SAM simulation program was then applied to these situations.

Experiment 1 showed that part-list cues that were delayed for short periods (15 or 30 seconds) inhibit recall to the same extent as immediate cues. Experiment 2 showed that cues that were delayed for longer periods (1, 2, or 4 minutes) had little effect on recall performance. Thus, the true effect of delayed part-list cues is to inhibit recall or have no effect depending on the length of the delay. Moreover, an updated version of the SAM program with a more reasonable set of assumptions was able to produce the correct pattern of results.

The major assumption that was changed for the present simulations was that the process of "rechecking" was included in the retrieval attempts, whereas Raaijmakers and Shiffrin did not include rechecking. During rechecking each of the recalled items are used as a cue for context-plus-cue sampling. If rechecking is not performed then there is little context-plus-cue sampling late in the retrieval attempt because few items are recalled and used as cues. When delayed part-list cues are introduced they are used for context-plus-cue sampling, and thus there is a profound change in the memory search. On the other hand, when rechecking is performed periodically during retrieval there is a mixture of context-based and context-plus-cue sampling. Thus, when delayed part-list cues are introduced they do not cause a dramatic change in the retrieval process.

Therefore, it is possible that the presence or absence of rechecking will alter the effects of delayed part-list cues.

A third experiment was performed to test this hypothesis. Raaijmakers and Shiffrin (1980) have suggested that verbal recall represents a situation where little or no rechecking occurs during retrieval. With verbal responding the subjects cannot view their previous responses, and thus the opportunity to use the recalled items for sampling is reduced. In the third experiment subjects attempted verbal recall either with no cues, with immediate part-list cues, or with cues delayed for short or long periods. The results showed that cues introduced after 3 minutes of recall reliably increased recall performance. Cues delayed for shorter periods (15 seconds or 30 seconds) showed a slight (nonsignificant) inhibition effect, while cues introduced after 1 or 2 minutes had little effect. Thus, delayed part-list cues do have a positive effect when they are delayed for long periods under conditions of verbal responding.

Running the SAM program without the process of rechecking did not produce a positive effect of delayed part-list cues. The program could produce a postive part-list cuing effect if a large number of samples were allowed, but with this assumption the program incorrectly predicted a cross-over of the free recall and immediate cues functions. Raaijmakers and Shiffrin (1981) predicted a postive effect of delayed part-list cues because they simulated recall without including rechecking and only examined the final performance levels after a large number of samples. Under these conditions both immediate and delayed part-list cues have a positive effect. However, if the number of samples is limited (as is necessary to correctly model the effects of immediate cues) then the SAM program cannot correctly model the effects of long-delay cues and verbal responding.

Thus, if the number of samples is limited, the SAM theory correctly predicts the effects of delayed part-list cues found with written recall, and most of the effects found with verbal recall. The SAM theory also provides a reasonable explanation for these effects. The inhibitory effect of short-delay cues can be explained by the same mechanism that was used to explain the effects of immediate cues. That is, the cues induce a bias for sampling clusters that tend to have at least one cue, while free recall subjects will still sample some clusters that have no cues. However, this does not explain why delayed cues fail to have a positive effect under written responding conditions. The part-list cues should provide access to some items that have not been recalled. It is clear that all the recallable items have not been sampled when the short-delay cues are introduced because the recall functions are far from the asymptote. It is possible, however, that all the strong and useful inter-item associations have been accessed when the cues are introduced ~~so~~ new retrieval routes are not provided. That is, delayed part-list cues may fail to facilitate recall because the associative links they provide are too weak to support recall. This suggests that if part-list cues are introduced during recall and they have no effect, there must be few useful inter-item associations available. Any increases in recall beyond this point must be due to context-only sampling.

Perhaps if longer lists were used in which there were more inter-item associations than could be sampled during a normal retrieval attempt, then the delayed cues might be facilitative. In fact, the literature (e.g., Park, 1980; Roediger, 1974; Wood, 1969) has shown that if there is a definite structure to a list, and if immediate cues are selected such that they give access to portions of the structure that might not be accessed, then the cues will be facilititative. The same generalization may hold for delayed part-list cues: they may only facilitate recall if they activate useful associative links. Thus, it might be possible to get a positive effect of delayed cues if a large categorized list is used and the cues provide access to categories that are not normally accessed.

This might also explain why there is a positive effect of long-delay cues under verbal responding conditions. The process of rechecking was proposed because during normal free recall each recalled item is not used to its full potential. Rechecking ensures that each associative link is explored, but without rechecking there may be useful links that have not been exploited. Delayed part-list cues, however, may cause some of these under-used associations to be accessed, and this produces an increase in recall.

A major difference between verbal and written recall is the difference in response monitoring. During written recall subjects are able to monitor their responses and use their previous answers as cues. This is not possible (or occurs to a lesser extent) during verbal recall. This process of response monitoring during recall deserves further research. As a first step, I have conducted an experiment where the presence and absence of response monitoring has been combined with the part-list cuing manipulation (free recall versus part-list cues). The subjects typed their responses at a computer terminal and the video display was divided in half. The top of the screen was either blank during recall or part-list cues were presented. Also, the bottom of the screen was either blank during recall or the previous responses made by the subjects were displayed. The subjects in this experiment performed two study-test trials under the same recall conditions, but with different lists of words.

The results showed a three-way interaction of Recall Condition X Response Monitoring X Trial. On the first trial the monitoring subjects showed a positive part-list cuing effect, whereas the non-monitoring subjects showed a slight negative cuing effect. This pattern was completely reversed on the second trial. Now the monitoring subjects showed a strong negative part-list effect, whereas the non-monitoring subjects showed a positive effect. Obviously, further research is needed to clarify these results, but they do suggest that response monitoring might be very important during recall, and may alter the effects of part-list cues.

It is important to realize that the delayed part-list cues used in Experiments 1, 2, and 3 (and the simulations) were a mixture of words that had been previously recalled and new words that had not been recalled. Perhaps the effects of delayed part-list cues are dampened by the fact that the "old" cues provide no new associative links because these items have already been recalled and used as cues. It might be useful to discriminate between "old" and "new" delayed cues to determine if "new" cues might have a positive effect where "old" cues do not. In fact, in Allen's (1969) experiment a stronger positive effect was found for unrecalled cues than for recalled cues. In contrast, Slamecka (1968, Experiment 5) only used unrecalled delayed part-list cues and failed to get any effect. In any event, the nature of the delayed cues deserves further research.

A general problem with the SAM simulations of part-list cuing is that they showed a convergence (or cross-over) of the free recall and immediate cues recall functions during the retrieval attempts whereas none was seen in the human data. In order for the theory to correctly model the part-list cuing effects it had to be assumed that only 60 samples were made during a retrieval attempt. With this assumption the model was able to correctly simulate all the recall curves from the first three experiments, except for the long-delay condition with verbal responding. However, all the predicted effects were much smaller than those shown in the empirical data (and reported in the literature).

The fact that SAM predicts a convergence or cross-over of the free recall and immediate cues curves may be problematic for the theory. There is no indication in the current set of data or the literature (e.g., Roediger et al., 1977) that the part-list cuing effect dissipates as a retrieval attempt progresses. However, the prediction may be correct and subjects might show the convergence if they were encouraged to continue their recall efforts for a long period. Roediger and Thorpe (1978) have shown that subjects' recall performance will continue to improve during very long recall periods. Also, there is some evidence that part-list cuing effects do dissipate when recall is tested in a second uncued test. Basden et al. (1977) showed that part-list cues inhibited recall on an initial test, but on a later test when the subjects were asked to recall all the words, including the cues, no inhibition effect was seen. Perhaps the final test provides an extension of the retrieval attempt and the part-list cuing inhibition effect would vanish in the present experiments if the subjects recalled longer.

On the other hand, if the theory is intended to model recall performance under normal conditions then the curves should not converge. What may be needed is some kind of stopping rule that would stop recall before the curves converge. In the early simulations of the part-list cuing effect (Raaijmakers & Shiffrin, 1981) the total number of failures was used to determine the point at which recall stopped. The rule that was adopted (KMAX=30) resulted in about 50 samples, and this corresponds with the assumption that had to be made here (60 samples). The stopping rule was abandoned because it was felt that maximum performance levels were not being allowed. Perhaps the maximum performance of the simulation program is far more than that of the human subjects so the program must be stopped prematurely.

In general, there is a problem comparing number of samples in the simulations with time spent recalling in the human data. In some research (e.g., Gronlund & Shiffrin, 1986) it is assumed that the two variables are directly related, and some have even provided estimates for the amount of time needed for each sample. (Gronlund & Shiffrin, 1986, provide an estimate of approximately 1.8 seconds per sample, which means that a 5 minute recall period would correspond with 167 samples.) There is an implicit assumption of a linear relationship between number of samples and time. It is quite possible, however, that an exponential function may better characterize the relationship such that the time for each sample increases as the retrieval attempt progresses (perhaps due to fatigue or weaker strengths of association). This possibility deserves exploration.

In summary, the present research on delayed part-list cues has discovered some important problems with the SAM theory. Although the theory correctly predicts that under normal responding conditions delayed part-list cues will either inhibit recall or have no effect depending on the length of the delay, the theory is incomplete or inaccurate because it is not able to correctly simulate the effects of long-delay cues under verbal responding conditions. Also, all the predicted effects are smaller than those in the experimental data. Finally, the theory persistently predicts a convergence (or cross-over) of the free recall and immediate cues functions when none is seen in the human performance. Thus, it must be concluded that the SAM theory requires further work.

Although the present research was designed to evaluate the SAM theory, it is also important for retrieval inhibition research in general. Experiment 1 showed that part-list cues that are delayed for short periods inhibit recall to the same extent as immediate cues. This suggests that the effect of part-list cues is not dependent on the beginning of the retrieval process. This may be problematic for any account that emphasizes a retrieval plan that is disrupted by the part-list cues.

Experiment 2 showed that part-list cues that are delayed for long periods have little effect on recall performance. Some researchers have suggested that part-list cues should facilitate recall because they may provide access to items that have not been remembered. In this account, some unknown inhibitory effect of the cues works against this tendency to facilitate recall. One might expect, then, that once uncued recall has become fruitless, the disruptive effect of the cues would no longer be present and the facilitative effect would emerge. Experiment 2 showed that part-list cues do not facilitate recall, even when they cannot be disrupting an ongoing retrieval effort.

Further, Tulving and Pearlstone (1966) claimed that a free recall procedure does not tap all the available memories because presenting category names after free recall had become fruitless led to an increase in recall. The present research has shown that delayed part-list cues do not have a similar facilitative effect. This suggests that with random words lists a free recall procedure might tap all the available memories.

The results of Experiment 3 suggest that response monitoring during recall may be more important than the past research has suggested. Previous research has paid little attention to the form of responding that is used for a recall test. The present research suggests that the ability to monitor the previous responses may be important, especially in part-list cuing situations. Further research on the role of response monitoring during recall is called for.

Finally, the present research has provided a set of evidence that must be explained by any general account of retrieval inhibition. With written recall conditions, delayed part-list cues inhibit recall with short delays and have no effect on recall with long delays. Further, the difference between written and verbal recall seems to be important for determining the effects of part-list cues, and part-list cues presented after a long period of verbal recall can facilitate remembering. The present research has added these phenomena to the list of findings that must be explained.

Manipulations of Item Strength

The SAM theory includes a ratio rule for determining the probability that an item will be sampled and recalled. The nature of this rule is such that items are in competition with each other based on their associative strengths. The result is that strong items in memory will tend to block the recall of weaker memories. Although the ratio rule has a lot of intuitive appeal, the experimental support for the rule is far from convincing. Some studies have shown blocking of weak items, while others have shown that the blocking might be an artifact of the procedures used. The fourth experiment reported here determined the degree to which strong items block the recall of weak items, and whether the SAM theory could predict the correct amount of blocking.

The fourth experiment showed that a manipulation of the level of processing of items during a second presentation will influence their probability of being recalled. It was claimed that this manipulation alters the items' strengths, and thus items with high probabilities of recall should block the recall of other (once-presented) items. However, in this study only a slight (nonsignificant) blocking effect was seen. The SAM simulation program was adapted to this experimental paradigm and the program predicted blocking of the same magnitude as the empirical data. Thus, the SAM theory was evaluated by applying it to a new experimental situation and the theory performed very well.

It might be useful to examine different manipulations of item strength. In this study the level of processing was used to manipulate strength but the SAM theory predicts the same effects for all types of strength. The amount of time allowed for study could be manipulated such that some items are presented for short periods and some for longer periods. Blocking would be seen if the higher recall for the items presented longer is at the expense of items presented quickly. If the current set of results are correct then there should only be a slight trade-off, and the SAM program should be able to model the results.

The results of Experiment 4 are also important for theories of memory other than SAM. Many memory theories (e.g., Anderson, 1983; Rundus, 1973) suggest that items in memory have different strengths of representation, and that items are in competition based on these strengths. This competition action has been used to explain a variety of phenomena (e.g., fan effects, inhibition in the A-B, A-D paradigm, etc.), and yet the present research suggests that the competition of items in memory is weak at best. Thus, the fundamental assumption of strength competition may be questionable, and it should the examined in future research.

The Role of Computer Simulations in Psychological Research

Computer simulations can be a useful tool for psychological research. Simulation techniques have a number of advantages over traditional research methods, but they also have a number of problems. One of the main advantages is that the process of developing a simulation program forces a theorist to use clear and detailed language. A computer will not accept vague statements or undeveloped proposals. A computer requires a detailed set of instructions in a step-by-step fashion. This forces a theorist to become very explicit about the assumptions and processes that make up a theory.

In developing the SAM theory and the accompanying program, Richard Shiffrin and his colleagues have had to take stands on a number of issues. For example, a number of theorists have proposed a fundamental distinction between short-term memories and long-term memories (e.g., Atkinson & Shiffrin, 1968). Others (e.g., Craik & Lockhart, 1972) have argued that such a distinction is not called for and the issue has not been resolved. In order to make a simulation program, however, the issue cannot be left unresolved. The SAM theory (and the program) includes both a short-term and a long-term store because the majority of the evidence suggests that they are appropriate. It is possible that further research will show that such a distinction is not appropriate. It is also possible, however, that the issue will never be resolved to everyone's satisfaction. Thus, a theorist could remain vague on the short-term/long-term memory distinction indefinitely. The process of developing a simulation program does not allow such vagueness, and thus one of its main advantages is that it forces decisions to be made.

A second advantage of computer simulations is that they allow the theorist to work at a level of complexity that may not be possible otherwise. Shiffrin's SAM theory has many complicated processes that are used during memory retrieval. Without the computer simulations it would be difficult to determine the effects of the various processes and their combinations. A related advantage is that simulations often produce quantitative results. This facilitates the process of theory evaluation because the results of the simulations should match the experimental results produced by human subjects. The process of theory revision is also facilitated since a theorists knows a revision is successful when the simulation data match the experimental data.

Shiffrin and his colleagues have used this feature of simulations extensively. The SAM program has been applied to a variety of experimental situations and when the simulated data have failed to fit the experimental data they have revised the theory until it does so.

Computer simulations also have a number of problems. The first has been described as the "transparency problem" (Raaijmakers & Shiffrin, 1980). As a theory (and the simulation program) become more complex, it becomes difficult for the audience (and even the theorist) to understand the workings of the program. This is especially true if a number of interacting processes are proposed where the results of the combinations are not predictable from the start. Shiffrin has attempted to deal with the transparency problem by exploring the full range of possible processing assumptions. By exploring all the possibilities and examining the behavior of the program under a variety of situations it is hoped that the workings of the program can be understood.

A second problem with simulation techniques is the issue of free parameters. A free parameter is an assumption or process in the program (and the theory) that is allowed to vary in order to fit a set of data or model an experimental situation. As a program is applied to more and more situations the number of free parameters often grows. This gives the impression that the program is able to produce any set of results if the correct combination of parameter values is chosen. The SAM simulations involve 10 or more free parameters, and so it could be argued that there is too much freedom in the theory.

The solution that Shiffrin used to solve this problem (and the approach that I adopted) is to develop a set of values for the free parameters based on empirical evidence, and then to hold constant as many parameters as possible across a variety of situations. Thus, in most of the simulations reported here only two parameters were ever varied (the criterion for abandoning a cue, LMAX, and the total number of samples). (CINC and IINC were special parameters that were developed to model a particular situation.) The SAM program was then applied to two new experimental situations (delayed part-list cues and manipulations of item strength) and it performed well. Better fits to the data might be possible if more parameters are allowed to vary, but the value of the theory would be less convincing.

This leads to the final problem of computer simulation techniques, the problem of "satisfaction". Just because a computer program is able to produce the same pattern of results as human subjects does not mean that it provides a satisfactory explanation for the psychological processes involved. What is needed is a computer program that produces the same results as human subjects, and does so in the same way. The problem is in determining that the program works in the same fashion as human subjects.

Obviously, this does not mean that the program works by the same physical mechanism as humans (the hardware). It does mean that the major processing assumptions must be the same for the program and the humans (the software). The approach that is adopted for the SAM theory is to include processes that seem to be reasonable on the basis of experimental evidence. The simulation program is then applied to a wide variety of situations and it is assumed that any differences between the processes used by the program and those used by humans will show up as discrepancies between the behavior of the program and the behavior of the subjects.

It is important to realize that computer simulations cannot be successful without empirical research. Programing allows a great deal of freedom during the implementation of a theory. A number of different programs can be made to produce the same patterns of results. A satisfactory program must contain processes and assumptions that are supported by empirical research. Thus, computer simulations can be a valuable tool for theory building and evaluation, but they are only useful in conjunction with empirical research.

SAM Simulations and Psychological Reality

The present research has shown that the SAM simulation program is successful in modelling some of the results produced by human subjects in two new experimental paradigms. The question that remains is whether the SAM theory provides a satisfactory explanation for the psychology involved in these situations. The program includes a number of processes and assumptions that are difficult to translate into psychological terms. One of the more problematic areas is the process of "sampling". In the program items are randomly sampled based on their strengths of association relative to the other items in memory. When an item is sampled its strength is evaluated and if the strength is high enough the item is recalled. It is not clear how many samples should be allowed during a retrieval attempt. This is especially important since the present research showed that the results of the program differ depending on the number of samples that are assumed.

The problem is one of translating the sampling used in the computer program into psychological terms. We do not know how sampling relates to the processes subjects use when they are recalling. Thus, we do not know what the correct total number of samples should be, or even whether sampling is the correct process to propose. The solution is to operationalize the concept of sampling as a concrete prediction and then evaluate the performance of the program.

Sampling is operationalized in the present research as the time spent recalling. Thus, any effects of time in a real experiment should be mirrored by effects of the number of samples in the simulations. What the present data show is that the SAM program is not completely successful in showing a correspondence between the number of samples and time spent recalling. The program predicts a convergence of the free recall and part-list cues recall curves as the number of samples increases, while no convergence is seen in the experimental data as the amount of time increases. Thus, the present results suggest that either the operationalization of sampling as time spent recalling is not correct, or the process of sampling itself is not a good description of the psychological reality.

In general, the way to determine if the processes included in a computer simulation program have any psychological reality is to apply the program to a variety of situations and evaluate its performance. If the processes in the program are not the same processes that humans use, then somewhere this discrepancy should become apparent. In the present research the SAM theory was applied to two new experimental situations and there were some discrepancies between the behavior of the program and the behavior of the subjects. This suggests that the SAM theory must be modified so that it will predict the data reported here.

Implications

Retrieval inhibition effects have been quite problematic for theories of human memory. Many memory theories predict facilitation in the situations where inhibition is actually seen. Research on the part-list cuing effect has convinced some researchers (e.g., Rundus, 1973; Slamecka, 1968) to question the assumption that inter-item associations are formed during list learning. However, work on the SAM theory (including the present research) has shown that retrieval inhibition can be explained using the very inter-item associations that have been questioned in the past. In the SAM theory retrieval inhibition occurs as a natural consequence of the inter-item (and context-to-item) associations. Thus, what has previously been a puzzle for association theories may actually be a natural consequence of the associations. The major implication of the present research is that retrieval inhibition may not be problematic for theories of memory that propose a network of associations. The SAM theory is an association theory and it is able to account for retrieval inhibition effects quite well. The theory does require some fine-tuning, but in general it is quite satisfactory.

Although the present research was primarily intended to evaluate a specific theory of human memory (the SAM theory), it does have some general implications as well. The SAM theory provides a general approach to human memory that may be useful in a variety of domains. Retrieval inhibition effects are interesting because they provide an opportunity to study memory failures in normal subjects. It is possible that these memory failures may provide some insight into the memory failures experienced by abnormal subjects (i.e., amnesics). The SAM theory assumes that memory failures are not due to a loss of the required memories but rather to a failure to retrieve the memories. It might be possible that memory failures of a more serious nature, such as amnesia, are also due to problems in retrieval rather than actual loss of the memories.

There is a growing field of research with amnesic subjects which supports this description of memory failure. Graf and Schacter (1985) have suggested a fundamental distinction between "explicit" and "implicit" tests of memory. Explicit memory tests, such as recall and recognition, involve conscious activation of information about specific experiences. Implicit memory tests, on the other hand, involve facilitation of performance on certain tasks (e.g., perceptual recognition or word-fragment completions) without the conscious recollection of memories. Research with amnesic subjects has shown that they may do poorly on explicit tests of memory, but their performance on implicit tests is often at normal levels. For example, Graf, Squire and Mandler (1984) tested amnesic and normal subjects using four methods of assessing memory. Although the amnesics were impaired on the free recall, recognition, and cued recall tests, their performance was at normal levels on a word completion measure. In fact, the cued recall and word completion tests involved the same retrieval cues (a word stem), but in the former case the subjects were instructed to remember the word that fit the cue while in the latter case the subjects were told to complete the cue with the first word that came to mind. Thus, these conditions differ in that one test (word completion) does not require conscious retrieval while the other test (cued recall) does. Since amnesics are only impaired on the explicit test (cued recall), this research suggests that amnesia may be due to retrieval failures rather than storage failures. It appears that the amnesic subjects have the needed information in memory, but explicit instructions somehow inhibit its retrieval. With implicit tests, on the other hand, they do not experience this inhibition. It might be useful to apply the retrieval inhibition paradigms to implicit tests of memory. It is possible that the inhibition seen with explicit tests will not be evident in implicit tests.

Retrieval inhibition research may also be useful for the study of problem solving and creativity. Many of the difficulties people experience during problem solving or the creative process may stem from a failure to retrieve the needed information rather than failure to have the information. Thus, as in the field of memory research, the retrieval environment may affect the chances of finding a solution or a creative result.

In the present research the process of response monitoring was found to be important for the retrieval process. There is some evidence that response monitoring is also important for creative problem solving. Penney and Winsor (1982) examined the creative process in a paradigm similar to a retrieval inhibition experiment. They were interested in the phenomenon of "incubation": the observation that an interruption or rest from work on a problem is often beneficial (e.g., Patrick, 1986). They asked subjects to generate synonyms for a number of words and the subjects were periodically interrupted. When the subjects returned to the task they were either provided with the responses they had generated previously, or they were not given their previous responses. Thus, some subjects were able to monitor their previous work while other subjects were not. The results of the experiment showed that subjects who did not monitor their responses showed a much larger incubation effect (a benefit from the interruptions) than those who did monitor their responses. It seems that the monitoring subjects were inhibited from finding new retrieval routes to a greater extent than the no-monitoring subjects. Perhaps response monitoring plays a similar role in memory retrieval and creative problem solving and further research should elaborate the similarities between these two fields of research.

Conclusions

The present research started with a puzzle. Why does related information often fail to facilitate recall, and sometimes actually inhibit recall? Raaijmakers and Shiffrin (1980, 1981) present a possible solution to the puzzle in the form of a complex theory of memory retrieval called SAM. This thesis examined whether the theory does provide an adequate solution. Two new experimental situations were developed and a set of important empirical results were reported. Experiments investigating the effects of delayed part-list cues showed that cues delayed for short periods inhibit recall while cues delayed for long periods do not. Also, the research showed that the form of responding (written versus verbal recall) is important for determining the effects of part-list cues. Further, an examination of the strength competition action of items in memory showed that the blocking produced by the presence of strong items is weak at best. The SAM theory was able to correctly model most of the findings, however, the program could not correctly simulate recall performance throughout the retrieval attempt. In particular, it could not simulate asymptotic recall performance while still producing correct part-list cuing effects. The theory must be revised such that it either produces the correct asymptotic recall curves or includes a principled way of terminating the retrieval attempt. Thus, it is concluded that the SAM theory requires some refinement, but it may eventually provide an adequate explanation for retrieval inhibition and a valuable general approach to human memory.

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APPENDIX

The SAM Simulation Program

This program was provided by Richard Shiffrin and Erich Smythe, and modified by the author. The program is written in VAX FORTRAN (V4.5-219) to run on a VAX 11/780 computer.

```
      PROGRAM NSAM3
C
C     THIS IS THE LATEST VERSION OF THE SAM MODEL FOR
C     PART-LIST CUING SENT BY SHIFFRIN IN AUGUST, 1986.
C     IT DIFFERS FROM THE EARLIER VERSION BY HAVING WEIGHTS
C     FOR THE CONTEXT AND CUE SAMPLING, AND IT HAS NO
C     STOPPING RULE.
C     INSTEAD, RECALL IS SCORED IN A CUMULATIVE FASHION
C     BASED ON THE NUMBER OF SAMPLES MADE UNTIL A MAXIMUM
C     NUMBER OF SAMPLES IS REACHED.
C
C     THIS IS THE IMPLEMENTATION OF THE DELAYED PART-LIST
C     CUING PROCEDURE.
C
C     RECHECKING EVERY 100 SAMPLES
C
C
C     THE VARIABLES ARE:
C     -----------------
C     N -- THE LIST LENGTH
C     N1 -- ALSO THE LIST LENGTH
C     R -- THE BUFFER SIZE
C     T -- THE STUDY TIME PER ITEM
C     COND -- THE CONDITION (1= CUED, 2= FREE RECALL,
C                  3=DELAYED CUES)
C     IB -- A FLAG FOR THE FIRST RECALL OF A CUE COUNTED AS
C            A FAILURE
C     IB1 -- A FLAG TO ONLY RECHECK RECOVERED CUES
C     IA -- A FLAG TO IMPLEMENT RECHECKING
C     TRIAL -- THE CURRENT SAMPLE NUMBER
C     MAXTRL -- THE MAX. NUMBER OF SAMPLES
C     SUBJECT -- SUBJECT COUNTER
C     NSIM -- THE NUMBER OF SIMULATED SUBJECTS
C     RECMAT (400) -- RECORD OF SUCCESS FOR EACH SAMPLE
C     RSTORE (3,400) -- RECALL DATA FOR ALL SUBJECTS IN BOTH
C                  CONDITIONS
C     RCHKREC -- SUCCESS ACCUMULATOR FOR RECHECKING
C     RCSTOR (3) -- RECHECKING SUCCESS COUNT FOR BOTH
C                  CONDITIONS
C     SEARCH (30) -- HAS THE ITEM BEEN SEARCHED?
C     SLONE (30) -- HAS THE ITEM BEEN SEARCHED BY CONTEXT
C                  ALONE?
C     SEARCHC (30,30) -- HAS THE ITEM BEEN SEARCHED WITH
C                  THIS CUE?
C     REC1 (30) -- IS THIS ITEM A CUE?
C     RREC (30) -- HAS THE ITEM BEEN RECALLED?
C     A -- THE SAM PARAMETER FOR CONTEXT STRENGTH
```

```
C       B -- THE SAM PARAMETER FOR INTER-ITEM STRENGTH
C       C -- THE SAM PARAMETER FOR SELF STRENGTH
C       D -- THE SAM PARAMETER FOR RESIDUAL STRENGTH
C       E -- THE SAM PARAMETER FOR INCREMENTING CONTEXT
C             STRENGTH
C       F -- THE SAM PARAMETER FOR INCREMENTING INTER-ITEM
C             STRENGTH
C       G -- THE SAM PARAMETER FOR INCREMENTING SELF STRENGTH
C       S (30,30) -- THE STORAGE MATRIX OF INTER-ITEM
C                    STRENGTHS
C       S1 (30,30) -- A BACK-UP STORAGE MATRIX
C       CNTXT (30) -- THE STORAGE MATRIX FOR CONTEXT STRENGTHS
C       CNTXT1 (30) -- A BACK-UP STORAGE MATRIX
C       CUEDEL -- CUE DELAY IN TERMS OF TRIALS (FOR COND 3)
C
C       ------------------------------------------------------
C       DECLARING THE VARIABLES
C       ---------------------
        INTEGER N, LMAX, COND, IB, IB1, IA, TRIAL, MAXTRL,
     $        SUBJECT, GO
        INTEGER RCHKREC, NSIM, R, CUEDEL, N1
        INTEGER RECMAT(400), RSTORE(3,400), RCSTOR(3),
     $        SEARCH(30)
        INTEGER SEARCHC(30,30), RREC(30), REC1(30), SLONE(30)
        INTEGER RECCUE(30,30)
        INTEGER SEED
        REAL A, B, C, D, E, F, G, T
        REAL S(30,30), S1(30,30), CNTXT(30), CNTXT1(30)
        CHARACTER*7 FNAME
C
        COMMON /GLOB/ N, LMAX, COND, IB, IB1
        COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
        COMMON /INCPAR/ E, F, G
        COMMON /STOREP/ A, B, C, D, R, T, CUEDEL
        COMMON /GN/ N1
        COMMON /STORE/ RSTORE, RCSTOR
        COMMON /SRCH/ SEARCH, SEARCHC, S, CNTXT, SLONE
        COMMON /SEED/ SEED
C
C       THE MAIN PROGRAM
C       ---------------
C        ** SET UP RANDOM NUMBER GENERATOR **
        READ *, SEED
C
        DO 40 CUEDEL= 10, 150, 10
        CALL INIT (MAXTRL, RSTORE, RCSTOR, IA, NSIM)
        N1=N
        DO 10 SUBJECT=1, NSIM
         CALL INITSUB (SEARCH, SEARCHC, RREC, REC1, RECCUE,
     $ CNTXT, CNTXT1, S, S1)
          DO 20 COND=1, 3
          CALL INITCON (TRIAL, MAXTRL, RECMAT, RCHKREC, SLONE)
          IF (COND .EQ. 1) CALL CUED (S, CNTXT, SEARCH,
     $       SEARCHC, RREC, REC1, RECCUE)
```

```
      CALL NOCUE (S, CNTXT, SEARCH, SEARCHC, RREC, REC1,
     $       RECCUE)
      CALL FINCON (SEARCH, SEARCHC, RREC, RECCUE, S, S1,
     $       CNTXT, CNTXT1)
 20   CONTINUE
     CALL FINSUB()
 10  CONTINUE
    CALL FINISH (NSIM)
 40 CONTINUE
    END
C
C   ------------------------------------------------------
    SUBROUTINE INIT( MAXTRL, RSTORE, RCSTOR, IA, NSIM)
C
C     ** INITIALIZES THE VARIABLES AND PARAMETERS **
C
    INTEGER  N, LMAX, IA, IB, IB1, I, J, R, NSIM, CUEDEL
    INTEGER RSTORE (3,*), RCSTOR(*)
    INTEGER*4 SEED
    REAL A, B, C, D, E, F, G, T
    COMMON /GLOB/ N, LMAX, COND, IB, IB1
    COMMON /INCPAR/ E, F, G
    COMMON /STOREP/ A, B, C, D, R, T, CUEDEL
    COMMON /SEED/ SEED
C
    N=30
    LMAX=3
    IA=0
    IB=0
    IB1=0
    R=4
    T=2
     DO 10 I=1, 3
     RCSTOR(I)=0
       DO 20 J=1, MAXTRL
       RSTORE(I,J)=0
 20    CONTINUE
 10  CONTINUE
    A=.10
    B=.10
    C=.10
    D=.01
    E=0.0
    MAXTRL=400
    NSIM=500
    F=E
    G=E
    END
C
C   ------------------------------------------------------
    SUBROUTINE FILBUF (MAT, MAT1, CNTXT, CNTXT1)
C
C     ** FILLS THE STORAGE MATRICES USING A RANDOM
C        REPLACEMENT BUFFER.  THE BUFFER IS CLEARED
C        GRADUALLY AFTER LEARNING. **
```

```
C
      INTEGER BUFFER(100), R, I, J, K, J1, K1, N, N1
      INTEGER*4 SEED
      REAL MAT(30,*), MAT1(30,*), CNTXT(*), CNTXT1(*), X
      REAL A, B, C, D, T
      COMMON /GN/ N1
      COMMON /STOREP/ A, B, C, D, R, T, CUEDEL
      COMMON /SEED/ SEED
C
      N=N1
       DO 10 I=1, N
        IF (I .LE. R) THEN
        BUFFER(I)=I
         DO 11 J=1, I
         CNTXT(J)=CNTXT(J)+ A*T
         MAT(J,J)= MAT(J,J)+ C*T
          DO 13 K=1, I
          IF (J .NE. K) MAT(J,K)=MAT(J,K)+ B*T
 13       CONTINUE
 11      CONTINUE
        ELSE
        X=RAN(SEED)
        K=X*R+1
        BUFFER(K)=I
         DO 12 J1=1,R
         J=BUFFER(J1)
         CNTXT(J)=CNTXT(J)+ A*T
         MAT(J,J)=MAT(J,J)+ C*T
          DO 14 K1=1,R
          K=BUFFER(K1)
          IF (J .NE. K) MAT(J,K)=MAT(J,K)+ B*T
 14       CONTINUE
 12      CONTINUE
        END IF
 10   CONTINUE
C
C      ** GRADUALLY CLEAR BUFFER **
C
       DO 15 K1=1,R
       K=BUFFER(K1)
       CNTXT(K)=CNTXT(K)+ A*T*(R-1.0)
       MAT(K,K)=MAT(K,K)+ C*T*(R-1.0)
         DO 16 J1=1,R
         J=BUFFER(J1)
         IF (K .NE. J) MAT(J,K)=MAT(J,K)+ B*T*(R-2.0)/2.0
 16      CONTINUE
 15    CONTINUE
C
C      ** SAVE FOR NEXT TIME AROUND **
C
      DO 17 I=1,N
      CNTXT1(I)=CNTXT(I)
       DO 18 J=1,N
       IF (MAT(I,J) .EQ. 0) MAT(I,J)=D
       MAT1(I,J)= MAT(I,J)
```

```
 18     CONTINUE
 17    CONTINUE
       END
C
C
C      -----------------------------------------------------
       SUBROUTINE INITCON (TRIAL, MAXTRL, RECMAT, RCHKREC,
     $                     SLONE)
C
C       ** INTIALIZES FOR EACH CONDITION **
C
       INTEGER TRIAL, MAXTRL, RECMAT(*), RCHKREC, I,
     $          SLONE(30)
C
       TRIAL=0
       RCHKREC=0
        DO 10 I=1, MAXTRL
        RECMAT(I)=0
 10     CONTINUE
        DO 20 I=1, 30
        SLONE(I)=0
 20     CONTINUE
       END
C
C      -----------------------------------------------------
       SUBROUTINE INITCUE (REC1, N)
C
C       ** INTIALIZES THE CUED CONDITION **
C
       INTEGER REC1(*), IX(400), I1, I2, I, N
       INTEGER*4 SEED
       REAL X
       COMMON /SEED/ SEED
C
        DO 10 I=1,N
        IX(I)=I
 10     CONTINUE
        DO 20 I=1,N
        X=RAN(SEED)
        I1=((N+1)-I)*X+I
        I2=IX(I)
        IX(I)=IX(I1)
        IX(I1)=I2
 20     CONTINUE
       X=RAN(SEED)
       I1=N*X+1
        DO 30 I=1,15
        I2=I1+I
        IF (I2 .GT. N) I2=I2-N
        REC1(IX(I2))=1
 30     CONTINUE
       END
C
C      -----------------------------------------------------
```

```
      SUBROUTINE INITSUB (SEARCH, SEARCHC, RREC, REC1,
     $    RECCUE, CNTXT, CNTXT1, S, S1)
C
C      ** INTIALIZES EACH SUBJECT **
C
      INTEGER SEARCH(30), SEARCHC(30,30), RREC(30),
     $         REC1(30), I, J, N
      INTEGER RECCUE(30,30), N1
      REAL S(30,30), S1(30,30), CNTXT(30), CNTXT1(30)
      COMMON /GN/ N1
C
      N=N1
       DO 10 I=1,N
       SEARCH(I)=0
       RREC(I)=0
       REC1(I)=0
       CNTXT(I)=0.0
         DO 20 J=1,N
         S(I,J)=0.0
         RECCUE(I,J)=0
         SEARCHC(I,J)=0
 20      CONTINUE
 10    CONTINUE
      CALL FILBUF(S,S1,CNTXT,CNTXT1)
      END
C
C     ----------------------------------------------------------
      SUBROUTINE NOCUE (S,CNTXT, SEARCH, SEARCHC, RREC,
     $                    REC1, RECCUE)
C
C      ** CONTEXT ONLY SAMPLING
C        IF THERE IS A SUCCESSFUL RECALL, USECUE IS CALLED.
C
      INTEGER I, COND, IB, SAMPLE, N, LMAX, DCFLAG, TRIAL
      INTEGER RECMAT(400), RCHKREC, MAXTRL, RECCUE(30,*)
      INTEGER SEARCH(*), SEARCHC(30,*), RREC(*), REC1(30)
      REAL S(30,*), CNTXT(*), SUM, XA(30)
      REAL A, B, C, D, T
      INTEGER R, CUEDEL
      LOGICAL DONE, RECALL, SUCC
      COMMON /GLOB/ N, LMAX, COND, IB, IB1
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
      COMMON /STOREP/ A, B, C, D, R, T, CUEDEL
C
C
      DCFLAG=0
 10   IF (.NOT. DONE()) THEN
C
C     ** IMPLEMENTATION OF DELAYED PART-LIST CUES **
C
       IF ((COND .EQ. 3) .AND. (DCFLAG .EQ. 0) .AND.
     $     (TRIAL .GT. CUEDEL)) THEN
       DCFLAG=1
       CALL CUED (S,CNTXT,SEARCH,SEARCHC,RREC,REC1,RECCUE)
       END IF
```

```
C
      CALL SAMPAR(CNTXT, SUM, XA)
      SUCC= .FALSE.
 20   CONTINUE
       IF ((MOD(TRIAL,100) .EQ. 0) .AND. (TRIAL .NE. 0))
     $ CALL RECHECK (S,CNTXT,SEARCH,SEARCHC,RREC,REC1,
     $              RECCUE)
      I=SAMPLE(SUM,XA)
      IF (DONE()) RETURN
      IF((RREC(I).NE.1)) THEN
       IF (RECALL(0,I)) THEN
       RREC(I)=1
       CALL RECSUC(I,REC1)
       CALL INCXT(CNTXT(I), S(I,I))
         IF ((COND .EQ. 2) .OR. (REC1(I) .NE. 1) .OR. (IB
     $      .EQ. 0)) THEN
         SUCC= .TRUE.
         CALL USECUE (I,S,CNTXT,SEARCH,SEARCHC,RREC,REC1,
     $             RECCUE)
         END IF
       END IF
      END IF
C
      IF ((.NOT. DONE()) .AND. (.NOT. SUCC)) THEN
      GOTO 20
      ELSE
      GOTO 10
      END IF
      END IF
      END
C
C     ---------------------------------------------------
      SUBROUTINE USECUE(I,S,CNTXT,SEARCH,SEARCHC, RREC,
C    $                    REC1, RECCUE)
C
C     ** SAMPLING USING A RECALLED ITEM **
C
      INTEGER I,J,L,SAMPLE,LMAX,COND,IB
      INTEGER SEARCH(*), SEARCHC(30,*), RREC(*), REC1(*),
     $        RECCUE(30,*)
      INTEGER TRIAL, MAXTRL, RECMAT(2,400),RCHKREC
      REAL S(30,*), CNTXT(*), SUM, XA(30)
      LOGICAL DONE, RECALL, SUCC
      COMMON /GLOB/ N, LMAX, COND, IB, IB1
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
C
      L=0
 10   IF ((.NOT. DONE()) .AND. (L .LT. LMAX)) THEN
       CALL SAMPARC (CNTXT,S,I,SUM,XA)
       SUCC=.FALSE.
 20   CONTINUE
       IF ((MOD(TRIAL,100) .EQ. 0) .AND. (TRIAL .NE. 0))
     $  CALL RECHECK (S,CNTXT,SEARCH,SEARCHC,RREC,REC1,
     $              RECCUE)
      J=SAMPLE(SUM,XA)
```

```
      IF (DONE()) RETURN
      IF ((RREC(J) .EQ. 0)) THEN
       IF (RECALL(I,J)) THEN
       RREC(J)=1
       RECCUE(I,J)=1
       CALL RECSUC (J,REC1)
       CALL INC1 (I,J,RECCUE,S,CNTXT,SUM,XA)
         IF ((COND .EQ. 2) .OR. (REC1(J) .NE. 1) .OR. (IB
     $        .EQ. 0)) THEN
         SUCC=.TRUE.
         END IF
       END IF
      END IF
C
      IF (SUCC) THEN
      I=J
      L=0
      GOTO 10
      ELSE
      L=L+1
       IF ((.NOT. DONE()) .AND. (L .LT. LMAX)) GOTO 20
       END IF
      END IF
      END
C
C     -----------------------------------------------------------
      SUBROUTINE CUED (S,CNTXT,SEARCH,SEARCHC, RREC, REC1,
     $               RECCUE)
C
C      ** DOES SEARCH USING PART-LIST CUES
C     FIRST, THE CUES ARE SELECTED
C
      INTEGER I,J,COND,N,IB,LMAX,SAMPLE
      INTEGER SEARCH(*), SEARCHC(30,*),RREC(*),REC1(*)
      INTEGER TRIAL, MAXTRL, RECMAT(2,400),RCHKREC
     $        RECCUE(30,*)
      REAL S(30,*), CNTXT(*), SUM, XA(30)
      LOGICAL RECALL, DONE
      COMMON /GLOB/ N, LMAX, COND, IB, IB1
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
C
      IF (COND .EQ. 1) CALL INITCUE (REC1,N)
      IF (.NOT. DONE()) THEN
      DO 10 I=1,N
       IF (REC1(I) .EQ. 1) THEN
       L=0
       CALL SAMPARC (CNTXT, S, I, SUM, XA)
 20     IF (L .LT. LMAX) THEN
       IF ((MOD(TRIAL,100) .EQ. 0) .AND. (TRIAL .NE. 0))
     $  CALL RECHECK (S,CNTXT,SEARCH,SEARCHC,RREC,REC1,
     $              RECCUE)
        J=SAMPLE (SUM,XA)
        IF (DONE()) RETURN
          IF ((RREC(J) .NE. 1)) THEN
            IF (RECALL (I,J)) THEN
```

```
              RREC(J)=1
              RECCUE(I,J)=1
              CALL RECSUC (J,REC1)
              CALL INC1 (I,J,RECCUE,S,CNTXT,SUM,XA)
         IF ((REC1(J) .EQ. 1 ) .AND. (IB .NE. 0)) L=L+1
              ELSE
              L=L+1
              END IF
            ELSE
            L=L+1
            END IF
          GOTO 20
        END IF
       END IF
 10    CONTINUE
       END IF
       END
C
C      ------------------------------------------------------------
       SUBROUTINE SAMPAR (CNTXT, SUM , XA)
C
C       ** FOR SAMPLING WITHOUT CUES **
C
       INTEGER  I, N1, N
       REAL CNTXT(*), SUM, XA(*)
       COMMON /GN/ N1

C
       N=N1
       SUM=0
        DO 10 I=1,N
        XA(I)= CNTXT(I)
        SUM= SUM+ XA(I)
 10     CONTINUE
       END
C
C      ------------------------------------------------------------
       SUBROUTINE SAMPARC (CNTXT, S, I, SUM, XA)
C
C      ** FOR SAMPLING WITH CUES **
C
       INTEGER J, I, N, N1
       REAL CNTXT(*), S(30,*), SUM, XA(*)
       COMMON /GN/ N1
C
       N=N1
       SUM=0
        DO 10 J=1,N
        XA(J)= CNTXT(J) **.5 * S(I,J) **.5
        SUM = SUM + XA(J)
 10     CONTINUE
       END
C

C      ------------------------------------------------------------
```

```
      SUBROUTINE INC1 (I,J,RECCUE,S,CNTXT,SUM,XA)
C
C     ** INCREMENTS WITH CUE AND CORRECTS SAMPLE ARRAY **
C
      INTEGER I,J,RECCUE(30,30)
      REAL E,F,G
      REAL S(30,30), CNTXT(30), SUM, XA(30)
      COMMON /INCPAR/ E,F,G
C
      CALL INCXT (CNTXT(J), S(J,J))
      IF ((RECCUE(J,I) .EQ. 0) .AND. (I. NE. J))  S(I,J)=
     $          S(I,J) +F
      S(J,I) = S(I,J)
      SUM= SUM - XA(J)
      XA(J) = CNTXT (J) **.5   *  S (I,J) **.5
      SUM = SUM+ XA(J)
      END
C
C     -----------------------------------------------------------
      SUBROUTINE INCXT (CNTXT, SELF)
C
C      ** INCREMENTS CONTEXT AND SELF STRENGTH **
C
      REAL CNTXT, SELF, E, F, G
      COMMON /INCPAR/ E, F, G
C
      CNTXT = CNTXT+E
      SELF = SELF +G
      END
C
C     -----------------------------------------------------
      SUBROUTINE RECSUC (ITEM, REC1)
C
C     ** RECORDS SUCCESSES DURING NORMAL RECALL **
C
      INTEGER ITEM, TRIAL, RECMAT(400), REC1(*)
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
C
      RECMAT (TRIAL) = 1 - REC1 (ITEM)
      END
C
C     -------------------------------------------------------
      SUBROUTINE RECSUCR (ITEM, REC1)
C
C       ** RECORD SUCCESSES DURING RECHECKING **
C
      INTEGER ITEM, TRIAL, RECMAT(400), REC1(*), RCHKREC
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
C
      RCHKREC= RCHKREC + (1- REC1(ITEM))
      END
C


C     ---------------------------------------------------------
```

```
      SUBROUTINE RECHECK (S,CNTXT,SEARCH,SEARCHC,RREC,REC1,
     $                    RECCUE)
C
C     ** DOES THE RECHECKING **
C
      INTEGER SEARCH(*), SEARCHC(30,*), RREC(*), REC1(*)
      INTEGER KSEAR(30), LSEAR(30), L1, I, J, L
      INTEGER SAMPLE, LMAX, N, COND, IB, IB1, RECCUE(30,*)
      REAL S(30,*), CNTXT(*), SUM, XA(30)
      LOGICAL RECALL, DONE
      COMMON /GLOB/ N, LMAX, COND, IB, IB1
C
      L1
      REAL S(30,*), CNTXT(*), SUM, XA(30)
      LOGICAL RECALL, DONE
      COMMON /GLOB/ N, LMAX, COND, IB, IB1
C
      L1=0
       DO 10 I=1,N
       LSEAR(I)=0
         IF ((RREC(I).EQ.1) .OR. ((COND.NE.2) .AND.

     $   (REC1(I).EQ.1) .AND. (IB1 .NE. 0))) THEN
         KSEAR(I) =1
         ELSE
         KSEAR(I)=0
         END IF
 10   CONTINUE
 20   CONTINUE
       DO 30 I=1,N
         IF (KSEAR(I) .EQ. 1) THEN
         L=0
         CALL SAMPARC (CNTXT, S, I, SUM, XA)
 40        IF (L .LT. LMAX) THEN
           J=SAMPLE (SUM,XA)
             IF (DONE()) RETURN
             IF ((RREC(J) .EQ. 1)) THEN
             L=L+1.
             ELSE
        IF (RECALL(I,J)) THEN
        RREC(J)=1
        RECCUE(I,J)=1
        LSEAR(J)=1
        L1=L1+1
        CALL INC1 (I,J,RECCUE,S,CNTXT,SUM,XA)
        CALL RECSUC (J,REC1)
          IF ((COND .NE. 2) .AND. (REC1(J) .EQ. 1) .AND.
     $        (IB .NE. 0)) L=L+1
        ELSE
        L=L+1
        END IF
       END IF
       GOTO 40
      END IF
      END IF
```

```
 30   CONTINUE
C
C      ** RECECK ANY RECALLED BY RECHECKING **
C
       IF (L1 .NE. 0) THEN
       L1=0
         DO 50 I=1,N
         KSEAR(I)= LSEAR(I)
         LSEAR(I)=0
 50      CONTINUE
       GOTO 20
       END IF
      END
C
C     -----------------------------------------------------
      SUBROUTINE FINSUB
C
C      ** DOESN'T DO VERY MUCH **
C
      I=0
      END
C
C     -------------------------------------------------------
      SUBROUTINE FINCON (SEARCH, SEARCHC, RREC, RECCUE, S,
     $    S1, CNTXT, CNTXT1)
C
C     ** FINISH RECALLING **
C
      INTEGER RREC(*), RECCUE (30,*), SEARCH(*)
      INTEGER COND, I,J,TRIAL, MAXTRL, SEARCHC(30,*)
      INTEGER RECMAT(400),  RCHKREC, RSTORE(3,400)
      INTEGER RCSTOR(3)
      REAL S(30,*), S1(30,*), CNTXT(*), CNTXT1(*)
      COMMON /GLOB/ N, LMAX, COND, IB, IB1
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
      COMMON /STORE/ RSTORE, RCSTOR
C
       DO 10 TRIAL= 1,MAXTRL
       RSTORE(COND,TRIAL)= RSTORE(COND,TRIAL)+ RECMAT(TRIAL)
 10    CONTINUE
      RCSTOR(COND)= RCSTOR(COND) +RCHKREC
C
       IF (COND .NE. 3) THEN
       TRIAL=0
         DO 30 I=1,N
         SEARCH(I)=0
         RREC(I)=0
         CNTXT(I)=CNTXT1(I)
           DO 20 J=1,N
           RECCUE(I,J)=0
           SEARCHC(I,J)=0
           S(I,J)=S1(I,J)
 20        CONTINUE
 30      CONTINUE
       END IF
```

```
      END
C
C     -----------------------------------------------------
      SUBROUTINE FINISH (NSIM)
C
C      ** OUTPUTS THE RESULTS **
C
      INTEGER RSTORE(3,400), RCSTOR(3)
      INTEGER NSIM, MAXTRL, I, J, RECMAT(400), CUEDEL, R
      INTEGER TRIAL, RCHKREC
      REAL MEAN(3), ACCUM(3), A, B, C, D, T, E, F, G
      COMMON /STORE/ RSTORE, RCSTOR
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
      COMMON /STOREP/ A, B, C, D, R, T, CUEDEL
      COMMON /INCPAR/ E, F, G
C
      DO 5 I=1,3
      MEAN(I)=0.0
      ACCUM(I)=0.0
 5    CONTINUE
C
       WRITE (*,99)
 99   FORMAT ('1  SAM SIMULATION OF DELAYED CUES',/,
     $  ' RECHECK EVERY 100',/,/)
      WRITE (*,100) A,B,C,D,E,CUEDEL,NSIM
 100  FORMAT ('   A= ', F6.4, ' B= ', F6.4, '   C= ', F6.4,
     $ '   D= ',F6.4, '   E=F=G= ',F6.4,/,'  CUE DEL= ',I3,
     $ '   NSIM= ',I4, /,/)
      WRITE (*,101)
 101  FORMAT (1X, 'MEAN PROPORTION RECALLED',/,/,
     $        ' SAMPLES', 6X,
     $        'CUED', 8X, 'FREE', 6X, 'DELAYED CUES',  /)
       DO 20 J=1, MAXTRL
         DO 10 I=1,3
         ACCUM(I)=ACCUM(I) + RSTORE(I,J)
 10      CONTINUE
           IF (MOD(J,10) .EQ. 0) THEN
              DO 15 I=1,3
              MEAN(I)= (ACCUM(I)/NSIM)/15
 15           CONTINUE
           WRITE (*,102) J, MEAN(1), MEAN(2), MEAN(3)
 102     FORMAT (2X, I4,6X, F8.5, 6X, F8.5, 6X, F8.5)
           END IF
 20   CONTINUE
C
      END
C
C     =====================================================
C     ********   THE FUNCTIONS **********
C
      FUNCTION SAMPLE (SUM, XA)
C
C      ** SAMPLES AN ITEM **
C
      INTEGER SAMPLE, N, N1, TRIAL, RECMAT(400), RCHKREC
```

```
      INTEGER*4 SEED
      REAL SUM, XA(30), X, X1
      LOGICAL DONE
      COMMON /GN/ N1
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
      COMMON /SEED/ SEED
C
      N=N1
      TRIAL=TRIAL+1
      X1=0
      X=RAN(SEED)
         DO 10 SAMPLE=1,N
         X1=X1 + XA(SAMPLE)/SUM
           IF (X .LE. X1) RETURN
 10      CONTINUE
      END
C
C     -----------------------------------------------
      FUNCTION RECALL (CUE, ITEM)
C
C      ** THE RECOVERY RULE **
C
      INTEGER SEARCH(30), SEARCHC(30,30), CUE, ITEM,
     $         SLONE(30)
      INTEGER*4 SEED
      REAL CNTXT(30), S(30,30), SITEM, SCUE
      LOGICAL RECALL
      COMMON /SRCH/ SEARCH, SEARCHC, S, CNTXT, SLONE
      COMMON /SEED/ SEED
C
       IF (CUE .EQ. 0) THEN
         IF (SLONE(ITEM) .EQ. 1) THEN
         RECALL= .FALSE.
         ELSE
         SLONE(ITEM)=1
           IF (SEARCH(ITEM) .EQ. 1) THEN
           RECALL = (RAN(SEED) .LE. (1.0 - EXP(-
     $                CNTXT(ITEM)*.5)))
           ELSE
           RECALL = (RAN(SEED) .LE. (1.0 - EXP(-
     $               CNTXT(ITEM))))
           END IF
         END IF
       ELSE
         IF (SEARCH(ITEM) .EQ. 0) THEN
         SEARCH(ITEM)=1
           IF (SLONE(ITEM) .EQ. 1) THEN
           SITEM=0
           ELSE
           SITEM= CNTXT(ITEM)
           END IF
         ELSE
         SITEM=0
         END IF
C
```

```
      IF (SEARCHC(CUE,ITEM) .EQ. 0) THEN
      SEARCHC(CUE,ITEM)=1
      SCUE = S(CUE,ITEM)
      ELSE
      SCUE=0
      END IF
    RECALL= (RAN(SEED) .LE. (1.0 - EXP(-SITEM*.5 -
   $         SCUE*.5)))
    END IF
   END
C
C     ------------------------------------------------------------
      FUNCTION DONE()
C
C      ** DETERMINES IF IT IS TIME TO STOP **
C
      INTEGER TRIAL, MAXTRL, RECMAT(400), RCHKREC
      LOGICAL DONE
      COMMON /RECORD/ TRIAL, MAXTRL, RECMAT, RCHKREC
C
C
      DONE= (TRIAL .GT. MAXTRL)
      END
```